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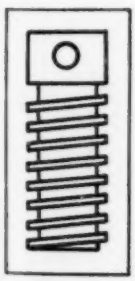

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METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER.)

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METALLURGIA

THE BRITISH JOURNAL OF METALS.
INCORPORATING "THE METALLURGICAL ENGINEER."

FEBRUARY, 1943 VOL. XXVII. No. 160

The Scientific Worker and Industry

IT has been rightly said that research is the systematic exploration of the unknown. Discovery and invention do not spring full-grown from the brains of men, but are the practical results of long and arduous work. The rare occasions when discoveries are made by accident belong largely to the past, to those times when there was little or no prior knowledge upon which to base experiments or ideas, but inspiration or accident then formed the basis for continuous development and much of the work involved consisted in labelling the avenues investigated and reporting the results to assist further investigators. Systematic exploration avoids confusion, reduces the possibility of premature conclusions, indicates the often unexpected influence of one factor upon another, and results in the final application of a discovery or development to the greatest benefit of mankind.

In all the branches of industry, investigations are continually in progress to establish and develop new means for improving and increasing production; it is this continual striving after improvements to increase the material resources of the world for the benefit of mankind that is the duty of the scientific worker, and the measure of success achieved is, to a large extent, the measure of progress. It is true, of course, that with the present social structure the results obtained by scientific workers are available for evil purposes, of which the present war is sufficient evidence; also a system operates by which benefits arising from investigations are reserved by one company or organisation. Ultimately, however, progress is effected.

War intensifies research work, and a great number of investigations that have been carried out since the present war began, or are in progress, will be directed to peace-time activities, and however much the energies of individual firms or organisations may be directed to the successful prosecution of the war, attention will also be given to the future, and the works chemist or metallurgist will have an essential part to play in the schemes developed. It can be said, for instance, that the study of metals is as yet in its infancy, in spite of the voluminous and magnificent work which has been accomplished. Metallurgical progress will depend upon the way in which the difficult conditions, inseparable from this work, can be manipulated; so much in development and application depends upon technique, and this in turn is governed by policy. This aspect of the subject was discussed by Mr. W. C. Devereux at a recent conference of the Association of Scientific Workers. Mr. Devereux has given considerable attention to the problem of how best to utilise the scientific workers in a commercial organisation, and he briefly described the procedure of his own companies, which employ about 600 people on the laboratory and development staffs.

The Controller of Laboratories, himself a scientist, is a member of the Board of Directors, and is thus familiar with all the main policy questions. He takes part in the direction of business and is in a position to bring the scientific point of view to bear at the very top of the administration. The actual broad planning of the work of the laboratories and the application of their findings and recommendations, is in the hands of a Technical Committee, comprising the technical, production, financial, and sales executives, who meet once in three months. The administration of research and development is the concern of the Executive Committee of which the Controller is chairman. This Committee is always available, but meets regularly once a month, and, in turn, is advised by numerous technical sub-committees, each dealing with a particular branch of the work in hand, and meeting at varying intervals according to whether or not the work under discussion is of a fundamental character or a process investigation. These committees are made up of those members of the laboratory staff actually responsible for carrying out the work, and, where necessary, representatives from the works. In addition, the laboratory staff are in constant contact with the management in dealing with the day-to-day problems of production and quality control; indeed, every stage of manufacture is under the control of the scientific body.

Unfortunately, laboratories on such a scale are the exception in industry, and under the existing system it is necessary to keep the bulk of the results obtained as far as possible for the benefit of the one company, but Mr. Devereux expressed the view that in the future there will be a swing-over from independent research to co-operative research in industry. Before this can take place, however, there must be radical changes in the present arrangements. Research associations are provided with totally inadequate funds to carry out more than a minute proportion of the research which is needed by the particular industries they serve, and they do not get nearly enough collaboration from the firms in those industries. If industry and the Government could be persuaded to increase their subscriptions to not less than ten times the amount at present subscribed, the increased investment would promote greater interest from member firms, and they would certainly begin to make those demands for results that are essential to give the necessary drive. In the non-ferrous industry, for instance, this would amount to about half a million pounds. With this support, £10,000 would be well spent in creating one of the most remunerative positions in the industry for the Chief Executive of the Association, in order to obtain the services of a man who would direct the work with the utmost speed and, at the same time, be capable of standing up to leaders of industry. Behind this leader there would be built up a really first-class team of research workers, who should be the best men available, and should keep in very close touch with industrial development and with the personnel of the companies they serve. The scale of remuneration should be at least as high as that in industry.

Scientific workers have played a great part, and will play an even greater part in increasing production and the development of industry in the near future, but it is believed that by increasing research on a co-operative plan, as outlined, the tendency would be greatly to increase the fruitfulness of human industry. It is recognised, of course, that the war period up to the present has shown a remarkable increase in production, but careful thought is necessary to direct these developments to peaceful channels and in preventing surplus labour retarding and clogging the wheels of progress.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

Zinc Alloys Die-Casters' Association.

THERE has been a marked tendency in recent years for the formation of associations in industry, and the fact that their numbers have increased must be taken as evidence that their value has been appreciated. It is easy to see that there are certain advantages to be gained from the pooling of effort and ideas, the benefit of accumulated experience and the concentration instead of the dispersal of activity.

The formation of the Zinc Alloy Die-Casters' Association, which was briefly announced in our last issue, is an example of this phase in industrial progress. Among its principal aims is the improvement in the technique of zinc alloy die-casting, and also to promote a wider knowledge of the particular properties of such castings. It will investigate and make known to its members new developments in industrial practice. In addition, and particularly as a war-time activity, the Association can represent the industry in discussion with certain departments of the Government.

To be able to speak with authority an association must comprise the great majority of the important producers, and also must be represented by people of standing in the industry. The Zinc Alloy Die-Casters' Association* is well up to the standard in these essentials. Most of the leading producers are members, and its elected officers for the past year are :—Chairman, Mr. R. Whitehead, of the Wolverhampton Die-Casting Co., Ltd., and deputy chairman, Mr. H. Ferguson, of Metal Castings, Ltd.

The advantage of an association of this kind is that in it the industry has a staff of people devoting their whole time to problems of general interest to the industry. This is just another example of that method of specialisation which industry itself has developed. Division of Labour, in other words, has entered the sphere of administration and research. Executives in industry in former years were obliged to fit in among their other immediate tasks the duty of considering general problems of long-term planning and research. With the delegation of some responsibility to the Association comes a greater freedom for the responsible people in industry to devote themselves to the relatively short-term problems of improvement in production and the organisation of their own works.

But even in their day-to-day activities the Association can be of great assistance in co-ordinating their efforts both in production and research. Particularly in research the existence of an association makes possible the carrying out of simultaneous investigation by a number of technicians dispersed in the industry, and in this way the fullest advantage may be reaped from group research under varied conditions. There are wider issues in which the specialised activities of an association can be of value. For example, investigation and study of labour policy and relations may be usefully carried out by an association, which is able to draw upon the knowledge of the industry as a whole.

In a time when everyone is bringing forward plans for post-war development, it is difficult for an industry to be constructive on problems of long-term policy so long as there is no communication between its separate units. It is only possible for it to put forward a useful contribution to the discussion now going on with regard to post-war plans, if there is a co-ordinating and constructive body fully representative of the industry, which can help to produce, a coherent policy.

Although attention has been directed more particularly to an association directly concerned with the development of zinc die-castings, many other associations could be mentioned that are functioning to the benefit of a particular trade or industry and assisting users in obtaining more reliable products. But there is scope for much further development in this direction, as co-ordinated research and development would greatly help the future of diecasting.

* The Zinc Alloy Die-Casters Association is operating from the same offices as the Zinc Development Association, which are at Lincoln House, Turl Street, Oxford.

Forthcoming Meetings

Institute of Metals.

THE thirty-fifth annual general meeting of the above Institute will be held at 4, Grosvenor Gardens, London S.W. 1, on March 3, 1943, at 3 p.m. The official business at this meeting will embrace a consideration of the report of the Council for the year ended December 31, 1942 ; the Treasurer's report, and statement of accounts to June 30, 1942 ; the election of officers and members of Council and Auditors for the year 1943-44 ; and the transaction of the ordinary business of the Institute.

Following the normal business, the following papers will be presented for discussion :—

"The Properties of Commercial Coppers Containing Selenium, Tellurium, and Bismuth." By G. L. Bailey and A. P. C. Hallowes.

"The Effect of Selenium, Tellurium, and Bismuth on Deoxidised Copper for Tube Manufacture." By Maurice Cook and G. Parker.

"A Note on the Damping Characteristics of Some Magnesium and Aluminium Alloys." By L. R. Stanton and F. C. Thompson.

Members who propose to join the discussion of any of the above papers are asked to inform the Secretary, Mr. G. Shaw Scott, not later than March 1, mentioning the papers that they desire to discuss.

Sheffield Metallurgical Association.

A paper entitled "Molybdenum High-Speed Steels with a Note on Tipped Tools," will be presented by H. W. Pinder, at the Sheffield Metallurgical Club, 198, West Street, Sheffield, 1, on March 6, at 2-30 p.m.

Institute of British Foundrymen.

Lancashire Branch.

A paper entitled "Fluid Pressure in Moulds—Effect of Mixed Gases" will be presented by E. Longden, on March 6, at 3 p.m., at the Engineers' Club, Albert Square, Manchester.

A Metallurgical Centenery.

Lecture on Roberts-Austen.

To commemorate the birth, on March 3, 1843, of the distinguished metallurgist, Sir William Chandler Roberts-Austen, a lecture on his life and work will be given by Dr. S. W. Smith, C.B.E., on Wednesday, March 3, 1943, at 5-30 p.m., at the Institution of Mechanical Engineers, Storey's Gate, S.W. 1. The lecture is being arranged jointly by the Institution of Mechanical Engineers, the Iron and Steel Institute, and the Institute of Metals.

Sir W. C. Roberts-Austen was an honorary member of the Institution of Mechanical Engineers, and he conducted a notable series of researches for the Alloys Research Committee of that Institution ; he was a past-president of the Iron and Steel Institute, and his name is perpetuated in the literature of ferrous metallurgy by the word "austenite." As he died in 1902—six years before the Institute of Metals was formed—that Institute can claim no direct connection with Sir William ; but his concern with non-ferrous metals and alloys was very close, both as a teacher of metallurgy—he held the chair of metallurgy at the Royal School of Mines, South Kensington—and as Chemist and Assayer of the Royal Mint.

Dr. Smith, who in 1914 wrote a book, "Roberts-Austen : a Record of his Work," and who acted as Sir William's private assistant at the Royal Mint, is well qualified to deliver the Centenary Lecture, to which all members of the three institutions and others are warmly invited. No tickets are required for the lecture.

A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts

THIS report constitutes a summary of data resulting from the metallurgical examination of German and Italian aircraft engine and airframe parts by the Aero Components Sub-Committee of the Technical Advisory Committee to the Special and Alloy Steel Committee formed for this purpose. In this, the seventh of the series, the summary of the results of investigations on certain airframe components is continued; it includes spar and related components, wing root fittings, undercarriage parts, and parts of the control system.

The Sub-Committee responsible for these investigations and for this report comprise Mr. W. H. Dyson, Ministry of Aircraft Production; Dr. H. Sutton, Royal Aircraft Establishment; Dr. R. Genders, Superintendent, Technical Applications Metals, Ministry of Supply; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd.; Mr. H. H. Burton, The English Steel Corpn., Ltd.; Mr. W. J. Dawson, Messrs. Hadfield, Ltd.; Dr. W. H. Hatfield, F.R.S., Chairman, Brown-Firth Research Laboratories; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.; Dr. T. Swinden, the United Steel Companies, Ltd.; and Mr. G. Stanfield, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out from the beginning of the war until towards the end of 1941, but investigations have continued and are still in progress, and the work is being carried out meticulously. Naturally, no comparisons are made in the report with corresponding parts in British or American aircraft, neither are certain aspects, which the investigations have shown to be open to criticism, emphasised.

Section XIII (*Contd.*)—Airframe Components

B.—SPAR AND RELATED COMPONENTS

These constitute the following:—

1. Centre-section spar (within fuselage)—Me 110 (Report No. 53).
2. Centre-section spar flange—Junkers 88 (V. 4GS) (Report No. 104).
3. Centre-section spar flange—Junkers 88 (4D.M.R.) (Report No. 111).
4. Top and bottom flange from centre-section spar—Me 109 (Report No. 68).
5. Strips from top and bottom spar flanges—Me 110 (Report No. 51).

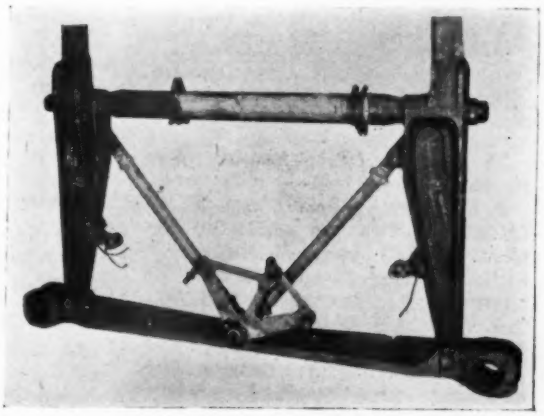
Figs. 13 to 16 illustrate the appearance of the above, and Table II summarises the essential metallurgical details.

A brief description of each is given below:—

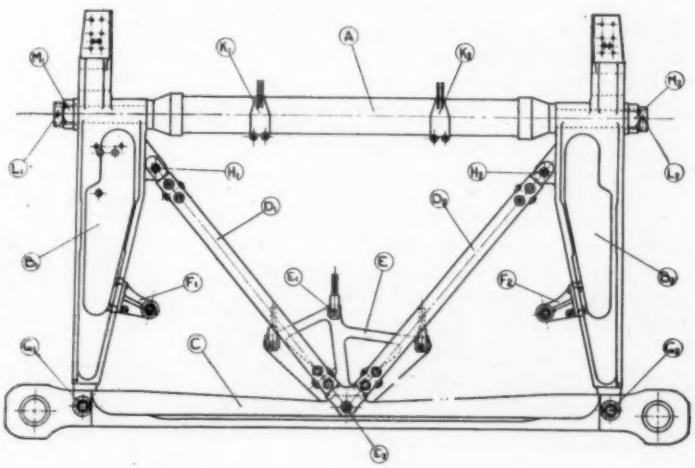
1. *Centre-section Spar within Fuselage* (*Fig.* 13), Me 110.—Complete details are given in the original report, with which is coupled Fig. 14.

2. *Centre-section Spar Flange* (Fig. 15), *Ju* 88 (*V.* 4*GS*).—This part was about five feet long by four inches wide, and painted greyish-green. At each of the hollow ends a seating was fitted, and these had originally a smooth machined finish. The method of retaining these seatings was not apparent (see 3 below).

The threaded rings at each end of the spar were made from an anodised aluminium alloy.



Figs. 13 and 14.—Centre section spar within fuselage—Me 110.



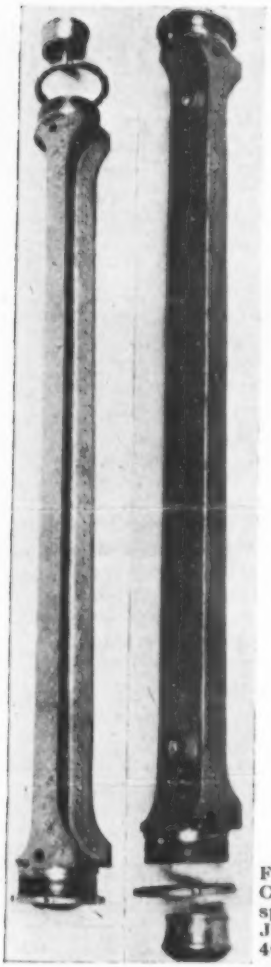


Fig. 15.—Centre section spar flange—Ju 88 (V. 4GS).

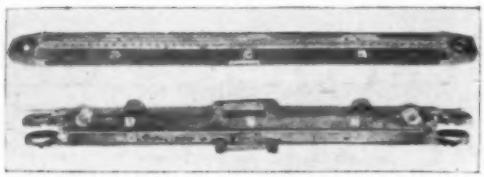


Fig. 16.—Top and bottom flange for centre-section spar—Me 109.

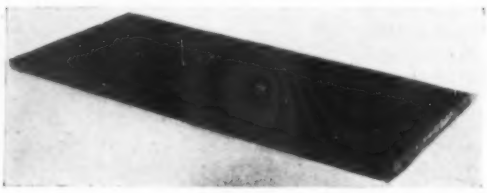


Fig. 17.—Strips for top and bottom spar flanges—Me 110.

The spar also carried two ball cups, riveted as shown by light alloy rivets.

3. *Centre-section Spar Flange, Ju 88 (4D.M.R.).*—This was similar to the above (No. 2) except at one end it carried a collar not included with the above sample. There were no ball cups.

4. *Top and Bottom Flange from Centre-section Spar (Fig. 16), Me 109.*—Both belonged to the centre-section spar of this aircraft and consisted essentially of a T-section beam with various fittings. The top flange terminated in a single boss at both ends, while the bottom flange was double. Both types contained swivel bearings.

5. *Strips from Top and Bottom Spar Flanges (Fig. 17), Me 110.*—These were portions of rectangular section strip containing a series of drill holes. Both pieces were painted grey.

Compositions

The majority of the steels used were of the chromium-molybdenum type with varying chromium contents and with and without vanadium, and in some cases a small nickel addition up to about 0·5%. The exceptions were under Report 104, where two parts had been made from 2/2 nickel chromium with molybdenum and another part under Report 111, where the molybdenum content was practically nil. (See Table I.)

TABLE I.—SPAR AND

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.
53	Me 110	Centre Section Spar.								
		A. Tube portion	0·25	0·29	0·60	0·005	0·011	Trace	1·03	0·21
		A. Screwed end	0·28	0·35	0·64	0·004	0·011	0·37	2·38	0·26
		B. Side member	0·35	0·35	0·68	0·006	0·013	0·38	2·57	0·25
		C. T-section strut	0·28	0·33	0·67	0·009	0·011	0·32	2·59	0·33
		G. Bolt connecting C to B	0·24	0 28	0 61	0 006	0·017	Trace	0·94	0·23
		D. Tubular sloping member	0·24	0·29	0·52	0·005	0·010	0·05	1·05	0·22
		D. End forked (to B)	0·29	0·33	0·59	0·010	0·009	0·11	2·30	0·15
		D. V-connecting piece	0·28	0·44	0·59	0·008	0·016	0·10	0·99	0·40
104	Ju 88 (V. 4GS)	Centre Section Spar Flange.								
		Spar	0·315	0·28	0·50	0·006	0·022	2·23	2·17	0·30
		End seating	0·32	0·32	0·41	0·010	0·012	1·90	1·94	0·36
		Ball cups	0·14	0·32	0·55	0·012	0·015	0·28	1·06	0·20
111	Ju 88 (4 DMR)	Centre Section Spar Flange.								
		Spar	0·31	0·32	0·62	0·010	0·012	0·32	2·27	0·29
		End seating	0·32	0·33	0·73	0·015	0·014	0·10	2·48	0·03
		Collar	0·33	0·34	0·66	0·006	0·013	0·31	2·95	0·27
51	Me 110	Strips from top Spar Flange	0·25	0·25	0·64	0·016	0·020	0·07	0·98	0·24
68	Me 109	Centre Section Spar Flanges.								
		Top	0·28	0·38	0·64	0·007	0·020	0·37	2·59	0·29
		Swivel—Outer	1·06	0·25	0·33	0·011	0·011	—	1·41	—
		Inner	0·85	0·30	0·24	0·029	0·014	—	1·33	—
		Bottom bridge	0·14	0·41	1·62	0·019	0·022	—	0·09	0·04

Method of Manufacture

All factors pointed to electric basic are steel manufacture, and all components had been made from hot-worked products except in one instance, viz., part D, under Report No. 53, which was found to be a casting (see Section XI on Castings)*.

* METALLURGIA, December, 1942.

Cleanness

On the whole the steel used in the manufacture of these parts was of a high order of cleanness.

Heat-Treatment

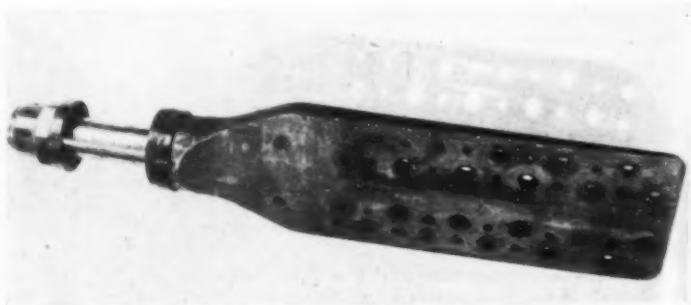
All the parts showed hardened and tempered structures excepting the ball cups under Report No. 104. In this case the steel appeared to have been normalised.

C.—WING ROOT FITTINGS

The components investigated were :—

1. Top and bottom root fittings, Me 110 (Report No. 51).
2. Small root fitting, port wing, Me 110 (Report No. 64).
3. Top and bottom root fittings, port wing, Me 109 (Report No. 69).
4. Top and bottom root fitting, front spar, Ju 88 (V. 4GS) (Report No. 107).
5. Wing root fitting, Ju 88 (4D.M.R.) (Report No. 113).
6. Wing root joint fitting, Heinkel 111 (H. 6, No. F. 8 bomber) (Report No. 112).

Table II is a summary of the essential date obtained on these parts, while Figs. 18 to 24 illustrate their general form and dimensions.



Figs. 18.—Top wing root fittings—Me 110.

General Description

1. *Top and Bottom Wing Root Fittings, Me* 110 (*Report No.* 51), *Figs.* 18 *and* 19.—Both consisted of a blade-like portion containing a number of drilled holes. The top fitting terminated with a spindle and screwed portion, while the bottom fitting had a seating containing a swivel bearing. Both were painted grey, except the ends already mentioned.

2. *Small Wing Root Fitting, Me* 110 (*Report No.* 64).—This merely consisted of two forked portions held together by a hexagonal nut. The exposed surfaces were covered with grey paint over an oxidised finish.

3. *Top and Bottom Wing Root Fittings, Me* 109 (*Report No.* 69), *Fig.* 20.—The top fitting was a T-section forging one end of which was connected with a forked portion parallel to the top of the T and containing holes for the spindle. The bottom component was somewhat similar, except that the end of the T-section connected with a flat cylindrical portion at right angles to the top of the T and carrying a spherical seated swivel bearing. Both parts had smooth surfaces covered with grey paint.

Fig. 19.—Bottom wing root fittings—Me 110.

4. *Top and Bottom Root Fittings (Ju* 88) (*Report No.* 107), *Fig.* 21.—These were very similar in design, the differences being only slight ones of dimensions. They consisted of two parts, one a forked member provided with a spherical seating at one end, on which was fitted a collar with an internal screw thread and spherical surface moving over the spherical seating of the forked member. The fittings were painted grey over a cadmium-plated surface.

5. *Wing Root Fitting, Ju* 88 (*Report No.* 113).—This was similar to item 107 above, the only essential difference being that the present one was zinc-plated and not cadmium-plated.

6. *Wing Root Joint Fitting, He* 111 (*Report No.* 112), *Fig.* 22.—The component consisted of two portions connected by a swivel joint, and there were 13 parts in all (see dimensional drawing). The whole exterior of the component and the interior of the tubular part were painted.

RELATED PARTS.

V.	Cu.	Al.	Inherent Grain Size.	YP.	MS.	El., %	R.A., %	Izod.	Hardness.	Special Remarks.
Nil	Trace	—	7 and 6	58·5	72·0	17·5	60·5	54, 54	315/321 B.H.	
0·17	0·12	—	Fine	68·2	73·5	19·5	58	39, 38	344/348 B.H.	
0·17	0·11	—	Fine	64·8	72·5	20	62	44, 45, 46	321/364 B.H.	
Nil	0·07	—	5	67·1	74·1	20·5	62	52, 52, 55	357/372 B.H.	
Nil	0·11	—	5	55·0	60·2	22·5	65·5	—	295/306 B.H.	
Nil	0·06	—	6	58·4	65·2	18·5	—	—	293/302 B.H.	
0·18	0·14	—	6	69·5	77·6	24	66	—	387/418 B.H.	
Nil	0·17	—	4 to 6	45·9	52·9	24	67	—	269 B.H.	Casting
0·12	0·12	0·02	4	—	82·3	16·9	50·5	15, 17, 13	364/375 B.H.	Structure coarse and overheated.
Nil	—	—	—	—	—	—	—	—	375/400 D.H.	
—	—	—	—	—	—	—	—	—	193/203 D.H.	
0·22	—	—	7	—	73·6	20·0	65	58, 58, 58	332–340	
0·22	—	—	6	—	—	—	—	—	302	
0·19	—	—	7	—	—	—	—	—	—	
Nil	0·13	—	6	52·1	57·8	20	53	—	285 B.H.	Bottom—similar
Nil	—	—	5 to 6	77·0	83·2	16·5	55	29 approx.	388/401 B.H.	Bottom—similar
—	—	—	4 to 5	—	—	—	—	—	383/411 B.H.	
—	—	—	4 to 5	—	—	—	—	—	769/798 B.H.	
—	—	—	7 to 8 (some 5)	—	—	—	—	—	197/207 B.H.	

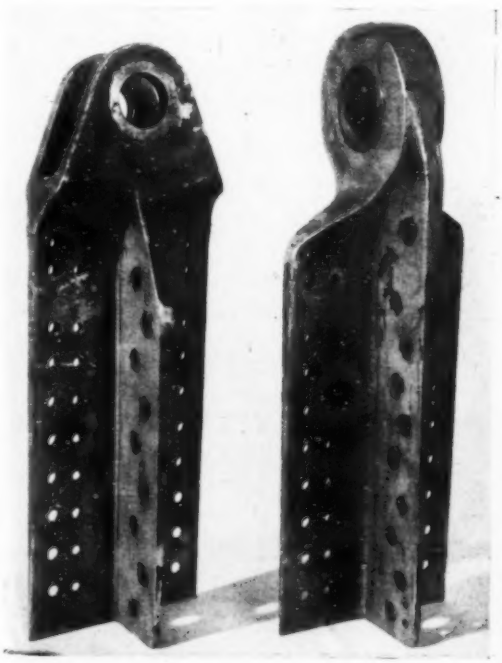
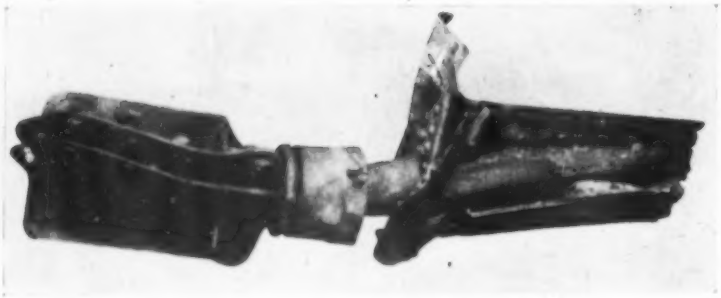


Fig. 20.—Top and bottom wing root fittings—Me 109

Fig. 21.—Top and bottom wing root fittings—Ju 88.



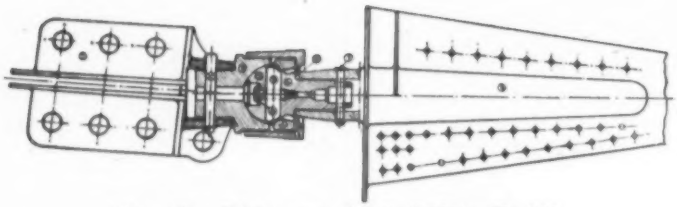


Fig. 22.—Wing root joint fitting—He 111.

Composition

The analyses were variable, but were mostly of the chromium-molybdenum class with or without vanadium. A few of the minor parts were nickel-chromium-molybdenum type.

Method of Manufacture

The bulk of the material used for these parts was considered to be of basic electric-arc manufacture. The subsequent procedure in making the parts was as follows:—

(1) Wing root fittings (Me 110) — made as forgings.

(2) Small root fitting (Me 110) — small fork machined from bar, large fork machined as forging.

(3) Wing root fitting (Me 109) — made as forgings.

(4) Wing root fittings (Ju 88) (V. 4G.S.) — made as forgings.

(5) Wing root fitting (Ju 88) (4D.M.R.) — made as forgings.

(6) Wing root joint fitting (Heinkel 111) — this component consisted of 13 parts, which are detailed in Table II. All parts but one were hot-worked products, and will not be discussed further. The other part (No. 1) was a good-quality casting (see Section X).

Cleanness

Most of the parts examined had a high order of cleanness.

Heat-Treatment

With the exception of the outer swivels, under Reports Nos. 51 and 69, all components were in the hardened and tempered condition.

Special Remarks

Generally speaking, the parts examined were of a high standard. The wing root fitting from a Junkers 88 (4D.M.R.) (Report No. 113), was in the nature of a check examination of similar fittings from a Junkers 88 (V. 4G.S.) aircraft reported earlier (Report No. 107). No deterioration in quality was observed except that the recent sample was zinc-coated and not cadmium-coated as previously.

D.—PARTS OF UNDERCARRIAGES

The undercarriage parts examined were as follows:—

1. From a Junkers Ju 88 aircraft.
   (*a*) Axle, knee-piece (Report No. 26), Fig. 23.
   (*b*) Torsion link (Report No. 25), Fig. 24.
2. From a Messerschmitt Me 110 aircraft.
   (*a*) Main undercarriage strut (Report No. 49), Figs. 26, 27 and 28.
   (*b*) Tail wheel assembly (Report No. 50), Figs. 29 and 30.
3. From a Messerschmitt Me 109 aircraft.
   (*a*) Main undercarriage strut (Report No. 65), Fig. 31.
   (*b*) Tail wheel assembly (Report No. 67), Figs. 32, 33 and 34.
   (*c*) Undercarriage bracket (Report No. 66), Fig. 36.

The items before being dismantled are shown in the attached photographs. In certain cases photographs have been included after dismantling.

Table III gives a summary of the essential details of each. For fuller details see Section X*.

* METALLURGIA, December, 1942.

TABLE II.—WING

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.
51	Me 110	Wing Root Fitting.								
		Top—Blade	0·32	0·31	0·72	0·005	0·007	0·59	2·42	0·30
		Nut	0·25	0·29	0·68	0·007	0·012	0·06	1·02	0·19
		Washer	0·29	0·17	0·63	0·014	0·009	0·08	2·53	0·20
		Bottom—Swivel (Outer)	1·04	0·32	0·33	0·004	0·008	0·15	1·51	0·06
64	Me 110	Small Root Fitting.								
		Large fork	0·24	0·28	0·57	0·010	0·010	0·13	0·96	0·20
		Small fork	0·29	0·17	0·59	0·013	0·012	0·09	2·48	0·21
		Nut	0·33	0·27	0·70	0·005	0·009	0·36	2·51	0·25
69	Me 109	Wing Root Fitting.								
		Top	0·30	0·31	0·58	0·004	0·006	0·11	2·62	0·43
		Bottom	0·24	0·23	0·56	0·007	0·011	0·05	0·97	0·19
		Swivel joint (outer)	1·01	0·27	0·27	0·027	0·018	<0·02	1·40	Trace
107	Ju 88 (V. 4G8)	Wing Root Fitting.								
		Top—Fork	0·29	0·27	0·54	0·013	0·020	0·04	2·55	0·27
		Collar	0·33	0·31	0·42	0·006	0·009	1·93	2·02	0·32
113	Ju 88 (4 DMR)	Wing Root Fitting	0·31	0·35	0·70	0·010	0·015	0·21	2·40	0·27
112	Heinkel 111–H6	Wing Root Joint Fitting.								
		1. Casting	0·23	0·40	0·66	0·008	0·017	0·05	0·93	0·14
		2. Seating	0·35	0·27	0·66	0·008	0·009	0·19	2·56	Nil
		3. Nut	0·30	0·25	0·59	0·008	0·017	0·27	2·39	0·33
		4. Collar	0·28	0·34	0·37	0·008	0·008	1·86	1·90	0·27
		5. Tube	0·23	0·20	0·61	0·010	0·011	0·14	1·01	0·16
		5a. Fin (thin)	0·26	—	0·60	—	—	—	0·99	0·13
		5b. Fin (thick)	0·27	—	1·08	—	—	—	0·67	Nil
		5c. Fin	—	0·29	0·62	—	—	0·17	1·10	0·19
		5d. Weld metal 1	—	0·30/0·43	0·55/0·62	—	—	0·16/0·28	1·07/1·18	0·19/0·39
		5e. Weld metal 2	—	0·29/0·41	0·75/0·78	—	—	0·20/0·24	1·14/1·22	Nil
		6. Internal screwed member	0·32	0·27	0·48	0·010	0·011	1·61	2·46	0·33
		7. Pin (through end of 5)	0·23	0·25	0·55	—	—	3·13	0·79	Nil
		8. Washer (on bolt 10)	Dead mild steel (carbon less than 0·1%)							
		9. Pin (through ball joint)	0·26	0·30	0·58	0·010	0·007	0·12	0·98	0·10
		10. Bolt (connecting two portions of ball joint)	0·28	0·29	0·71	—	—	0·06	1·00	0·14
		11. Washer (at joint end of 5)	Carbon steel (about 0·6% carbon)							
		12. Pin (joining 1 and 2)	0·19	0·17	0·69	0·208	—	0·02	0·03	Nil
		13. Hemispherical bearing	0·31	0·26	0·49	0·010	0·012	1·62	2·45	0·36

In the Ju 88 aircraft the knee-piece, which also formed the lower end of the shock absorber strut, was found to be a steel casting made in 0·23% carbon, 1% chromium, 0·25% molybdenum steel heat-treated to a tensile strength of 70 tons per sq. in. Castings of a similar type have been employed on the Me 110 and Me 109 main undercarriage struts, as shown in Figs. 23 and 25.

The axle in the Ju 88 fitting was a separate component, being held in by keys; but in the Me 109 and Me 110 fittings it was part of the casting. The torsion links and the head of the Me 109 strut also were steel castings. A full description of the properties of all these castings is given in Section X.

The axle in the Ju 88 fitting was made from a drawn tube of chromium-molybdenum steel containing 0·25% carbon, 1·03% chromium, and 0·24% molybdenum. A tensile test on a specimen from the axle gave values of 52·4 tons/sq. in. and 66·0 tons/sq. in. for 0·1% proof and maximum stress, with 11·5% elongation on 2 in. This axle had been zinc-coated. The axle on the Me 110 had been chromium-plated, but no surface treatment had been applied to the Me 109 axle.

The torsion link from the Ju 88 was a drop stamping in steel of the 0·4% carbon, 1% chromium, 0·25% molybdenum type heat-treated to give 0·1% proof stress and maximum stress values of 37·2 and 51·2 tons/sq. in., with 19% elongation on 2 in. The links from the Me 110 were also made of chromium-molybdenum steel, but with only 0·26% carbon. The tensile properties were, however, better than those obtained on the Ju 88 link, being 68·5 tons per sq. in. maximum stress with 22% elongation (on 4√A.).

Fig. 23.—Axle knee-piece and shock absorber strut—Ju 88.

The main undercarriage struts of the Me 110 and Me 109 have been completely dismantled and the properties of all the components determined. The number of parts involved is very large, and it is not intended to enter into a full description in this publication. It was found, however, that the majority of the steel parts had been made of steel of the 1% chromium, ¼% molybdenum type, with carbon contents ranging from 0·2% to 0·5%.

Fig. 24.—Torsion link—Ju 88.

The tensile strength values ranged from 61 to 73 tons per sq. in., with a normal degree of ductility.

Exceptions to the above were the plunger tubes on both struts and the radial support on the Me 110 strut.

These three components were made in steel containing 0·25 to 0·30% carbon, 2·5% chromium, 0·25% molybdenum, and 0·15 to 0·28% vanadium. The tensile strengths varied from 78 to 87 tons per sq. in., and the elongation values from 16 to 22% on 4√A.

The plunger tubes on both struts had been chromium-plated. On the Me 110 tube the thickness of chromium was 0·005 in. On the Me 109 tube the thickness was only 0·0016, and a very thin undercoating of nickel was present.

The chromium coatings had a fine lapped finish, and diamond pyramid hardness tests gave values of 642 (10 kg. load) for the Me 110 tube and approximately 840 (0·5 kg. load) for the Me 109 tube.

The tail wheel assemblies from the Me 110 and Me 109 aircraft have also been completely dismantled and investigated, but only the major components will be described here. It was found that with few exceptions the steel parts consisted of chrome-molybdenum steel, although the compositions show considerable variation.

In the Me 110 fitting the fork had been built up by welding together sheet material in chromium-molybdenum steel containing 0·26% carbon, 0·95% chromium, and 0·22% molybdenum. Welding rod of similar alloy content had been used. The fork had been welded to

ROOT COMPONENTS.

V.	Cu.	Grain Size.	Y.P.	M.S.	E. %.	R.A. %.	Izod.	Brinell Hardness.	Special Remarks.
0·12	Trace	6 to 7	71·9	77·8	20	60	46, 53	375/402	Bottom similar
Nil	0·13	6 to 7	—	—	—	—	—	311	
0·18	0·16	6	—	—	—	—	—	340/364	
Nil	0·12	7	—	—	—	—	—	256/257 (outer) 471/475 (inner)	Inner similar
Nil	0·13	7	58·2	61·0	17	61·5	—	302–311	
0·20	0·13	7 to 8	71·6	74·7	17	61·5	—	369–375	
0·17	0·09	Fine	—	—	—	—	—	364–375	
0·28	0·15	Fine	72·9	75·6	6 (B.O.P.)	57·5	31	364/418	
Nil	0·13	5 (some 3 and 4 grains)	74·0	77·8	14 (B.O.P.)	52·5	28	375/387	
Nil	0·10	Fine	—	—	—	—	—	286/293 (outer) 504/512 (inner)	Inner similar
0·33	0·17	About 7	51·2	58·4	21	65·5	71, 61, 71	283/302	Bottom wing root fitting similar
Nil	0·08	6 to 7	76·6	80·9	17	57	—	356/361	
0·15	0·15	—	—	—	—	—	—	302/336	
Nil	0·11	Mainly 1–2 and 5	55·7	56·9	20	54	—	255–269	
0·19	0·11	Probably fine	50·5	55·5	20	66	—	288–317 296–300 302–309	
0·2–	0·12	8 or finer	72·0	77·5	16·5	43·5	—	358–387	
Nil	0·09	6 and 7	69·0	74·3	15	52	—	351–364 358–354	
Nil	0·07	4 to 5	53·6	61·0	21·5	61·5	—	319, 327	
Nil	—	—	—	—	—	—	—	329–337	
0·13	—	—	—	—	—	—	—	319–325	
Nil	—	—	—	—	—	—	—	341–345	
Nil	—	—	—	—	—	—	—	—	
Trace	—	—	—	—	—	—	—	—	
Trace	0·07	6 to 7	68·0	78·3	17·5	62	—	350–404, 358	
Nil	0·12	3 to 6	—	—	—	—	—	280–282	
—	—	—	—	—	—	—	—	187–192	
Nil	0·09	6 to 7	—	—	—	—	—	288–296	
Nil	0·13	3 and 4	—	—	—	—	—	293–296	
—	—	—	—	—	—	—	—	415–421	
Nil	0·05	Probably fine	38·3	43·3	17	42½	—	207–208	
Trace	0·09	6	—	—	—	—	—	363–368	

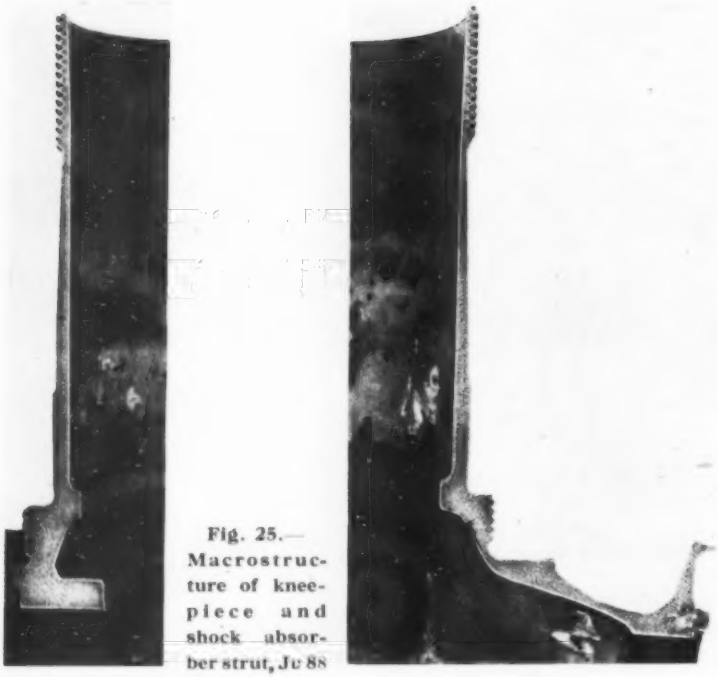
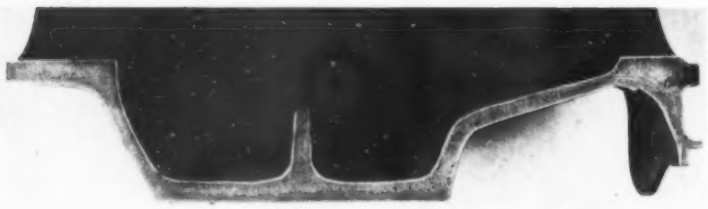


Fig. 25.—Macrostructure of knee-piece and shock absorber strut, Ju 88



the sliding tube, which had been machined from bar of similar chemical composition to that of the fork, and the tube and fork combined had been heat-treated after welding to a tensile strength of approximately 74 tons per sq. in.

In the Me 109 fitting the fork was a casting in chromium-molybdenum steel of the usual type. The part had been hardened and tempered to a tensile strength of 60 tons/sq. in., and was bolted to the sliding tube. The tube had been machined from a bar of chromium-molybdenum-vanadium steel similar in type to that used for the tubes in the undercarriage struts, and hardened and tempered to give tensile properties of the same order.

The main cylinders of both units were made in chromium-molybdenum steel, but whereas the one from the Me 110 had been heat-treated to a tensile strength of 70 tons/sq. in., that from the Me 109 possessed a tensile strength of only 47·2 tons/sq. in. A similar difference in tensile properties was found in the inner sleeves in the two components. In the Me 110 the part was made from 2% chromium-molybdenum-vanadium steel, and possessed a tensile strength of about 66 tons/sq. in. In the Me 109 unit it was made in the usual chromium molybdenum steel and possessed a tensile strength of only 43 tons/sq. in.

The main and auxiliary springs in the Me 110 unit and the main spring in the Me 109 unit were all made in silico-manganese steel containing:—

	%
Carbon	0·57 to 0·66
Silicon	2·60 to 2·87
Manganese	0·82 to 0·84

The springs had a diamond hardness ranging from 550 to 636. Surface decarburisation was present in the Me 109 spring, and the ends of both springs from the Me 110 had been softened to about 300 D.H. The surfaces of the springs had apparently been sand-blasted, and the springs appeared to have been cold-coiled from cold-drawn wire and then hardened and tempered.

The Me 109 undercarriage bracket (Report No. 66) consisted in the main of a 1% chromium-molybdenum steel casting with many subsidiary fittings of various analyses, details of which will be found in Section X. The casting, apart from two relatively unimportant defects, was sound and had been ground and/or machined over the whole of the accessible surface (see Figs. 35 and 36).

With the exceptions of the main cylinder of the Me 109 undercarriage strut and the inner cylinder of the Me 110 tail assembly, all the main parts were made in high-quality basic electric-furnace steel. In one or two of the basic electric steel parts the standard of cleanness was rather low. In general however, the steels were very clean.

TABLE III.—UNDERCARRIAGE COMPONENTS.

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.
26	Junkers 88	Undercarriage Assembly.							
		Shock absorber strut	0·23	0·45	0·64	0·004	0·005	0·02	0·94
		Knee-piece	—	—	—	—	—	—	—
		Axle	0·25	0·19	0·50	0·011	0·022	0·02	1·03
		Tube from inside axle	0·04	Trace	0·42	0·033	0·061	Nil	0·03
		Steel key	0·37	0·29	0·66	0·010	0·015	0·22	1·01
25	Junkers 88	Torsion link	0·43	0·25	0·53	0·023	0·013	0·12	1·12
		Torsion link—Steel bush	0·28	0·22	0·53	0·009	0·009	0·02	1·11
49 j	Me 110	Main Undercarriage Strut and Axle.							
		Plunger tube	0·25	0·38	0·45	0·011	0·008	0·10	2·53
		Cylinder tube	0·25	0·31	0·41	0·010	0·017	0·24	0·99
		Torsion link	0·26	0·235	0·60	0·007	0·014	0·29	1·01
		Axle—Single casting	0·26	0·39	0 64	0·004	0·010	0·11	0·98
		Knee-piece—Single casting	0·26	0·39	0·64	0·004	0·010	0·14	0·98
		Radial support	0·29	0·34	0·62	0·005	0·011	0·31	2·37
		Retraction arm	0·26	0·37	0·66	0·009	0·012	0·11	0·98
		Retraction bracket	0·29	0·33	0·71	0·005	0·013	0·09	0·89
50	Me 110	Tail Wheel Assembly—Barrel Portion.							
		Outer barrel	0·26	0·28	0·50	0·011	0·009	0·02	1·04
		Weld metal	—	0·28	0·56	—	—	0·06	0·81
		Registering unit steel pin	0·28	0·23	0·55	0·009	0·009	2·22	1·82
		Flanged end-plate	0·32	0·28	0·68	0·011	0·010	0·32	2·32
		Two setscrews (A8)	—	0·15	0·52	—	—	0·02	2·60
		Two setscrews (A10)	0·09	0·01	0·72	—	—	0·02	0·08

E.—PARTS OF CONTROL SYSTEMS

The following parts were examined :—

1. Main lead from control column — Me 110 (Report No. 55).

2. Control rod operating elevator tabs — Me 110 (Report No. 55).

3. Flap control tube — Me 109 (Report No. 70).

4. Flap control tube — Junkers 88 (4 D.M.R.) (Report No. 113).

5. Control rod (fuselage) — Junkers 88 (V. 4G.S.) (Report No. 107).

6. Auxiliary control column — Junkers 88 (V. 4G.S.) (Report No. 105).

7. Part of steel tube operating driving brake, Junkers 88 (V. 4G.S.) (Report No. 108).

8. Tail plane incidence adjustment crank, Junkers 88 (V. 4G.S.) (Report No. 108).

9. Rudder control wire — Me 109 (Report No. 71).

10. Spring (inside bomb door control tube) — Junkers 88 (Report No. 109).

These parts are illustrated in Figs. 37 to 48. Some of the components were non-ferrous types and have not been considered in this report. In addition, several components were composed of a multitude of small parts, so that for the purposes of this report only the major parts are dealt with. A more detailed list will, however, be found in Table IV.

A general description of the various components is outlined below :—

Figs. 26, 27 and 28.—Main undercarriage strut—Me 110.

1. *Main Lead from Control Column* (*Fig.* 37).—This consisted of a solid-drawn tube 14 mm. dia. reduced at the ends to 10 mm. dia. An 8 mm. dia. plain insert was fitted into one end, and into the other was fixed a screw carrying a square non-ferrous nut. The tubular portion was grey painted.

2. *Control Rod Operating Elevator Tabs* (*Fig.* 38).—In this case the component was a solid-drawn tube, 50 mm. dia., with a reduced end portion welded on to it. The extreme end of the latter carried a double ball bearing, and the tube also carried a bolt and nut just below the welded portion. The whole surface was painted grey.

3. *Flap Control Tube* (*Me* 109) (*Figs.* 39 *and* 40).—The flap control consisted of a thin seamless tube at one end of which a brass shank was fitted, and held with six rivets. A hollow steel shackle and screw operated within the shank on a double-start left-hand acme thread. The outer surface of the tube and exposed surface of the shank were coated with a light-green paint.

4. *Flap Control Tube* (*Ju* 88) (*Fig.* 41).—This consisted of a 35 mm. dia. tube with 1 mm. thick walls, to one of which had been welded a closed end-piece with an internal screw thread. The screwed end-piece carried a light alloy tube held in place by a screwed washer, which also fitted on the screwed end of the light alloy tube.

5. *Control Rod* (*Fig.* 42).—The control rod was a built-up construction consisting of two 20 mm. dia. tubes with external splines at one end and internal splines at the other. The two tubes were joined together by a plug round which

Continued on pages 132-133.

Mo.	V.	Cu.	Al.	Y.P.	M.S.	El., %	R.A., %	Izod.	Hardness.	Special Remarks.
0·25	Nil	0·10	Ti., 0·003	66·4	72·2	7 (on 2")	—	—	—	Single casting
—	—	—	Al., 0·063	67·9	69·5	3 (on 2·4")	—	—	—	Single casting
0·24	Nil	0·10	—	60·0	66·0	11·5 (on 2")	—	—	—	H. and T.
0·02	Nil	0·01	—	—	—	—	—	—	124/132	Hot-rolled
0·23	Nil	0·10	—	—	—	—	—	—	287/315 B.H.	Cold-worked
0·22	Nil	0·19	—	41·2	51·2	19 (on 2")	—	—	—	H. and T.
0·24	Nil	0·10	—	—	88 app'x.	—	—	—	—	H. and T.
0·27	0·25	—	—	—	78	22	61	—	354 (Steel) 642 (Cr. plate max.)	Chromium-plated H. and T.
0·24	—	—	—	—	73·5	17·5	53·5	36·5	284/351	H. and T.
0·19	—	—	—	—	68·5	22	62·3	—	318/337	Normalised.
0·20	—	—	—	—	75·0	8	25·5	—	673 max. Cr. plate 337/354 (Steel)	Chromium-plated, H. and T. cast
0·20	—	—	—	—	77·0	9	25	—	673 max. Cr. plate 366 (Steel)	H. and T. casting
0·26	0·15	—	—	—	87·0	18·5	56·7	—	396/412	Normalised
0·22	—	—	—	—	—	—	—	—	318/323	Normalised
0·18	—	—	—	—	—	—	—	—	324/336	H. and T. casting
0·24	Nil	—	—	—	—	—	—	—	302/321	Four bosses welded to end of barrel and two spindle bosses welded to barrel approx. similar. Two bosses welded to side of barrel—one 1% Cr-Mo, and the other 0·44% C steel (228 VDH).
0·26	—	—	—	—	—	—	—	—	—	
0·31	0·25	—	—	—	—	—	—	—	341	
0·22	0·18	—	—	—	—	—	—	—	364/387	
0·34	Nil	—	—	—	—	—	—	—	321/363	Two set-screws A.9 similar (all set-screws Cd. plated).
—	—	—	—	—	—	—	—	—	212/229	Six set-screws A.11 approx. similar (all set-screws Cd. plated).

Fig. 31.—Main undercarriage strut—Me 109.

was held in position a lever arm, the end of which carried a ball bearing.

6. *Auxiliary Control Column* (*Figs* 43 *and* 44).—This consisted of a thin-walled tube bent at right angles at a position approximately one-third of its length. Inserted and held by two screws to the longer section of the tube was a rubber-covered handle. Riveted to the shorter arm of the tube was a light alloy casing on to which a cap was screwed. The casing had an internal spline towards one end and a small nut and bolt attached to the wall of the casing, acting probably as a stop. Turning on a left-hand acme thread within the cap was a hollow steel cone and shaft, carrying a spring, a light alloy washer and ball race, ball bearings, and attached on the outer side of the cap to a light alloy knob by a taper pin.

The whole of the outer surface was painted dark green with a light-green undercoating.

Figs. 29 and 30—Tail wheel of Me 110, showing details and complete assembly.

7. *Part of Steel Tube Operating Diving Brake* (*Fig.* 45).—This part was merely a tube with two light alloy flanges riveted on at one end. The tube was painted green all over.

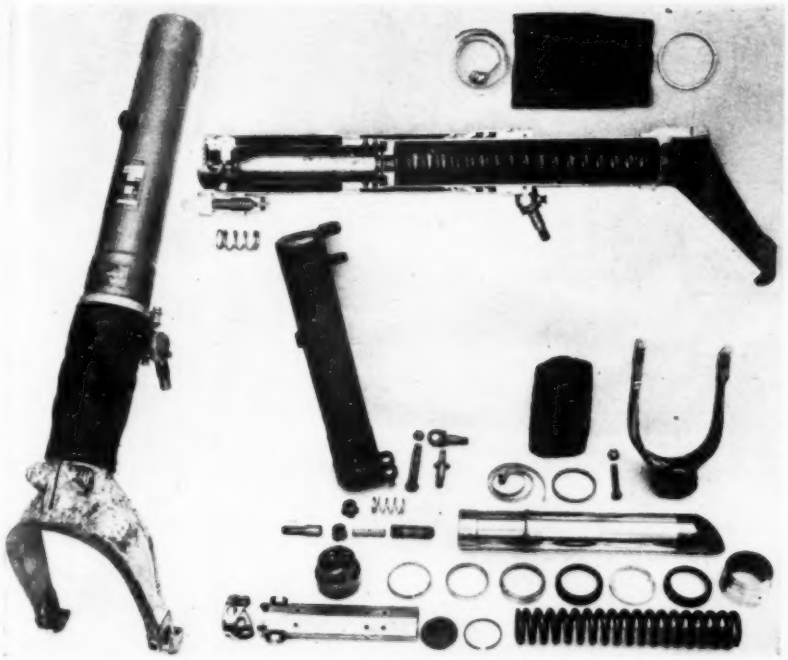
8. *Tail-plane Incidence Adjustment Crank* (*Fig.* 46).—The component consisted of a steel tube to which was welded a hollow V-shaped strut and a number of flanges (43 separate pieces of tube and sheet were thus welded together), and two links of non-ferrous metal attached to the flanges by pins, on which they were free to move. This was also painted green inside and out.

A general consideration of the results of the various metallurgical examinations are detailed below :—

TABLE III.—UNDER-

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.
65	Me 109	Undercarriage Strut.							
		Head	0·26	0·40	0·72	0·011	0·015	0·20	0·85
		Top cylinder	0·49	0·32	0·59	0·015	0·032	Nil	1·13
		Collar	0·26	0·22	0·58	0·012	0·010	0·03	1·02
		Bottom cylinder	0·41	0·29	0·56	0·014	0·024	0·05	1·16
		Torsion links (Upper)	0·23	0·44	0·66	0·018	0·010	0·12	0·86
		Foot	0·19	0·49	0·65	0·014	0·012	0·11	0·89
		Bearing bush (Outer)	—	0·30	0·81	0·026	0·020	0·30	1·01
		Bearing bush (Inner)	—	0·24	0·38	0·026	0·035	0·05	0·19
		Separator bush	0·27	0·29	0·56	0·017	0·015	0·06	0·99
		Piston	0·30	0·36	0·49	0·011	0·012	0·25	2·42
		Screw cap	0·32	0·24	0·49	0·01	0·01	1·92	1·92
66	Me 109	Undercarriage Bracket (Port).							
		Bracket casting	0·25	0·42	0·69	0·009	0·012	0·08	0·98
		Fittings—							
		Pivot spindle	0·30	0·36	0·59	0·009	0·006	1·92	1·83
		Connecting link	0·28	0·31	0·55	0·013	0·013	0·04	1·07
		Connecting link pin	0·31	0·27	0·46	—	—	1·73	2·00
		Coupling jaw	0·32	0·38	0·71	—	—	0·06	2·56
		Coupling pin	0·32	0·24	0·69	—	—	0·08	2·64
		Coupling pin spherical sleeve	1·05	0·34	0·32	—	—	0·12	1·63
		Coupling inner spherical bush	—	0·32	0·31	—	—	0·10	1·54
		Coupling outer spherical bush	—	0·27	0·64	—	—	Trace	0·21
		Catch details—side-plate	—	0·32	1·08	—	—	0·05	1·18
		Insert slide	0·18	0·24	0·93	—	—	0·09	1·17

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S.	P.	Ni.	Cr.
67	Me 109	Tail Wheel Assembly.							
		Main cylinder	0·27	0·20	0·65	—	—	0·16	1·07
		Horse-shoe wheel mounting	0·23	0·44	0·60	—	—	0·07	1·15
		Hollow ram	0·45	0·27	0·48	—	—	0·11	1·70
		Main-spring	0·66	2·87	0·84	0·016	0·017	0·02	0·01
		Stationary sleeve	0·30	0·27	0·72	0·010	0·017	0·11	1·15



Figs. 32, 33 and 34.—Tail wheel for Me 109, showing details, sectional structure, and complete assembly.

Fig. 37.—Main lead from control column—Me 110.

Fig. 39.—Flap control tube—Me 109.

CARRIAGE COMPONENTS.

Mo.	V.	Cu.	Al.	Y.P.	M.S.	El., %	R.A., %	Izod.	Hardness.	Special Remarks.
0·13	Nil	0·18	0·08	—	61·0	14·0	46	34, 38	—	Casting
0·20	Nil	0·04	0·06	—	66·4	16·0	34·2	—	—	
0·26	—	—	—	—	—	—	—	—	322 D.H.	
0·23	Nil	0·14	0·02	—	61·5	21·2	50·8	—	—	
0·18	0·05	—	—	—	67·0	16·5	35·0	47, 51	—	Casting lower approx. similar
0·24	0·05	0·18	0·02	—	52·6	17·5	43·4	70	—	Casting
0·32	—	—	—	—	—	—	—	—	825 D.H. (Case) 363 D.H. (Core)	Carburised inside and outside
Nil	—	—	—	—	—	—	—	—	847 D.H. (Case) 220 D.H. (Core)	Carburised outside only
0·20	—	—	—	—	—	—	—	—	214 D.H.	
0·23	0·28	—	—	—	84·5	16·7	37·3	—	—	Chromium-plated
0·19	—	—	—	—	—	—	—	—	388 D.H.	
0·12	Nil	0·10	0·08	61·2	66·1	12·8	—	—	—	
0·21	0·13	—	—	—	—	—	—	49	302/332 B.H.	
0·22	Nil	—	—	—	—	—	—	—	302/331 B.H.	Coupling jaw bush, coupling nut, and coupling pin nut approx. similar
0·35	Nil	—	—	—	—	—	—	—	352/363 B.H	
0·28	0·26	—	—	—	—	—	—	—	430/444	
0·34	0·33	—	—	—	—	—	—	—	351	
0·12	Nil	—	—	—	—	—	—	—	798/810 D.H.	
Nil	Nil	—	—	—	—	—	—	—	810/822 D.H.	
—	—	—	—	—	—	—	—	—	242/258 D.H.	
0·27	Nil	—	—	—	—	—	—	—	303/315 B.H.	
0·25	Nil	—	—	—	—	—	—	—	302/311 D.H. (Core) 823/890 D.H. (Case)	Carburised

Mo.	V.	Cu.	Al.	Inh'nt. Grain Size.	Y.P.	M.S.	El., %	R.A., %	Izod.	Hardness.	Special Remarks.
0·[illegible]	—	—	—	6—8	30·7	47·2	32·9	—	—	239/249 D.H.	
0·[illegible]	—	—	—	5—7	50·0	59·5	25·0	37·2	—	270/280 D.H.	Casting
0·[illegible]	0·18	—	—	5—6	66·4	74·1	20·0	—	—	350/360 D.H.	
—	—	—	—	—	—	—	—	—	—	636 D.H.	
0·[illegible]	—	—	—	4—6	34·6	43·23	35·5	—	—	224/240 D.H.	

Fig. 38.—Control rod operating elevator tabs—Me 110.

A.—TUBULAR COMPONENTS

Composition

All the material considered fell into the 1% chromium-molybdenum category, including the weld metal (Report No. 113).

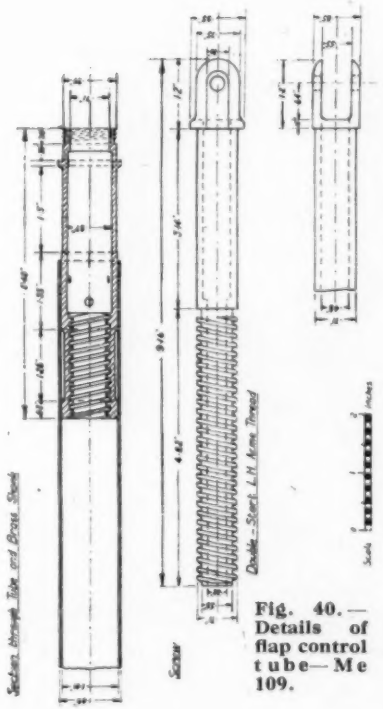


Fig. 40.—Details of flap control tube—Me 109.

TABLE IV.—PARTS OF CONTROL SYSTEM.

Report No.	Type of Aircraft.	Component.	C.	Si.	Mn.	S	P.	Ni.	Cr	Mo.	V.	Cu.	Inherent Grain Size.	YP.	MS.	E. %	R.A. %	Hardness.	Special Remarks.
55	Me 110	Main Lead from Control Column (Tube).																	
		Tube	0·21	0·09	0·51	0·035	0·015	0·019	1·06	0·18	Nil	0·06	4 to 5	40·1	45·7	27·5	—	202/212 B.H.	
		screwed insert	0·28	0·23	0·57	0·004	0·021	0·11	1·05	0·15	Nil	0·11	5 to 6 (bar No. 4)	37·0	46·5	31	73.5	225	
		Plain insert	0·29	0·30	0·63	—	—	<0·02	1·05	0·16	Nil	0·10	—	—	—	—	—	220	
		Control Rod Operating Elevator Tabs (Tube).																	
		Tube	0·26	0·32	0·51	0·004	0·007	<0·02	1·04	0·16	Ni	0·13	5 to 6 (some No. 4)	39·1	44·4	26·5	—	223/235	
		Closed end	0·27	0·28	0·61	0·007	0·009	<0·02	0·98	0·18	Nil	0·08	5 to 7	—	—	—	—	217/228	
		Ball-race—																	
		Bearing	1·14	0·21	0·40	—	—	0·20	1·33	Nil	Nil	—	—	—	—	—	—	810/823 D.H.	
		Bearing balls	1·03	0·34	0·27	—	—	<0·10	0·53	Nil	Nil	—	—	—	—	—	—	890/905 D.H.	
70	Me 109	Flap Control Tube.																	
		Tube	0·29	0·135	0·54	0·014	0·029	Nil	0·98	0·25	Nil	—	2 to 4 (mainly 3)	—	69·1	14·0	—	359 D.H.	
		Shackle and screw	0·29	0·295	0·64	0·018	0·014	0·08	1·07	0·17	Nil	—	4 to 7 (mainly 5 to 6)	—	—	—	—	309 D.H.	
113	Ju 88 (4 DMR)	Flap Control Tube.																	
		Tube	0·22	0·31	0·44	0·009	0·012	0·12	1·06	0·16	Nil	0·13	1 to 5 (mainly 1 to 3)	57·3	61·7	13·5	—	304/310	H. and T. after welding
		Closed-in end	0·34	0·39	0·79	—	—	0·15	1·09	0·19	Nil	0·16	4 to 6	—	—	—	—	327/331	
		Weld metal	—	0·4	0·18	—	—	0·29	1·13	0·15	Nil	—	5 to 6	—	—	—	—	—	
107	Ju 88 (V. 4G8)	Control Rod (Tube)	0·25	0·26	0·51	0·009	0·009	0·05	1·18	0·19	Nil	0·05	5 to 6 (a few No. 4 grains)	41·5	46·0	27·5	—	211/213	
105	Ju 88 (V. 4G8)	Auxiliary Control Column.																	
		Pt. 1—Tube	0·255	0·41	0·68	0·010	0·012	0·09	1·04	0·17	Trace	0·10	4 to 6 (mainly 5)	—	66·0	22·7	—	342/359 D.H.	
		Pt. 3—Cone & shaft	0·25	—	—	—	—	—	1·15	0·20	—	—	2 to 5 (mainly 3 to 4)	—	—	—	—	288/298 D.H.	
		Pt. 4—Spring	0·83	—	—	—	—	—	—	—	—	—	4 to 6 (a little grade 1)	—	—	—	—	547 D.H.	Patented and drawn
		Ball-bearings	0·42	—	—	—	—	—	13·40	—	—	—						602 D.H.	
108	Ju 88 (V. 4G8)	Tube Operating Diving Brake.																	
		Tube	0·28	0·28	0·65	0·011	0·011	0·12	0·92	0·21	Nil	0·24	—	—	—	—	—	207 B.H.	Cold-drawn and probably tempered
108	Ju 88 (V. 4G8)	Tail-plane Incidence Adjustment Cranks.																	
		Welded assembly	0·23/ 0·27	0·22/ 0·31	0·48/ 0·74	0·006/ 0·011	0·007/ 0·015	Trace/ 0·34	0·69/ 1·20	0·17/ 0·25	Nil	0·09/ 0·19	—	—	—	—	—	202/241 B.H.	Normalised after welding
		Large pin	0·26	0·30	0·58	0·014	0·010	0·10	1·17	0·23	Nil	0·13	—	—	—	—	—	311 B.H.	H. and T.
		Small pin	0·29	0·30	0·42	0·009	0·009	1·95	1·96	0·30	Nil	0·07	—	—	—	—	—	340 B.H.	H. and T.
		Eyebolt	0·25	0·32	0·55	—	—	0·10	1·20	0·22	Nil	0·15	—	—	—	—	—	320 B.H.	H. and T.
		Ball-race—																	
		Outer	1·02	0·32	0·27	—	—	Trace	1·25	Trace	Nil	0·09	—	—	—	—	—	890 D.H.	
		Inner	1·03	0·37	0·28	—	—	Trace	0·88	Trace	Nil	0·12	—	—	—	—	—	890 D.H.	
		Balls	1·00	0·28	0·30	—	—	Trace	0·63	Trace	Nil	0·18	—	—	—	—	—	856 D.H.	
		Cage	—	0·14	0·26	—	—	0·02	0·05	Nil	Nil	0·21	—	—	—	—	—	121/118 B.H.	
		Swivel bushes	0·26	0·30	0·58	0·006	0·010	0·06	1·08	0·25	Nil	0·11	—	—	—	—	—	293/311	H. and T.
		Miscellaneous nuts	0·38/ 0·40	0·19/ 0·35	0·49/ 0·79	—	—	Trace/ 0·10	0·02/ 0·22	Trace 0·03	Nil	0·04/ 0·20	—	—	—	—	—	207/255	
71	Me 109	Rudder Control Wire	0·17	0·17	0·62	0·015	0·013	Trace	0·02	Nil	—	—	1 to 4 (mainly 3)	75·0 (0·1% P.S.)	91·5	16·0	60·5	390/442 D.H.	
109	Ju 88 (V. 4G8)	Spring (inside bomb-door control tube)	0·82	0·14	0·60	0·021	0·006	0·08	0·07	Trace	Nil	0·12	1 to 6	—	—	—	—	449/469 D.H.	Patented and drawn

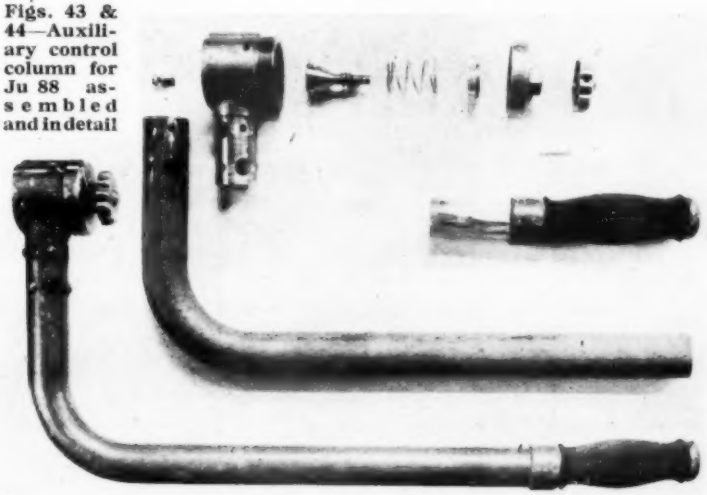
Figs. 35 and 36.—Undercarriage bracket assembled, and showing detailed construction—Me 109.

Fig. 41.—Flap control tube—Ju 88.

Fig. 42.—Control rod—Ju 88.

Fig. 45.—Part of steel tube operating diving brake—Ju 88.

Figs. 43 & 44—Auxiliary control column for Ju 88 assembled and in detail



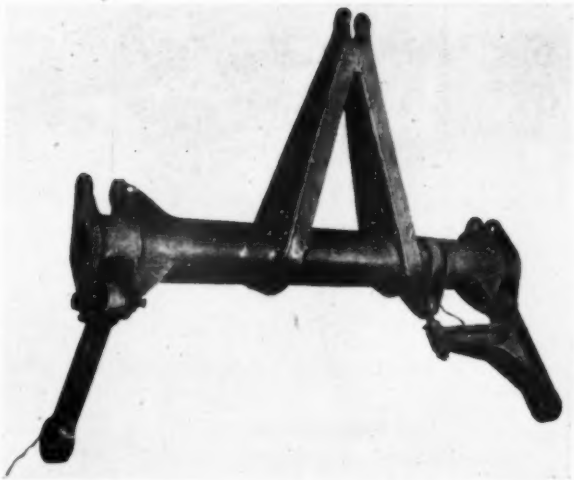


Fig. 46.—Tail plane incidence adjustment crank—Ju 88.

Fig. 48.—Spring—inside bomb door central tube—Ju 88.

Method of Manufacture

In all cases the steel was probably of basic electric-arc manufacture, and all components were made from hot-worked products. In the case of the tubular parts, these were made from solid-drawn tubes followed by heat-treatment.

Cleanness

In all cases the steel was fairly clean.

Heat-Treatment

Hardening and tempering treatments were carried out in the majority of cases. Where welding was used (Report No. 108 and 113), heat-treatment appeared to have been carried out subsequent to welding.

B.—WIRES AND SPRINGS, BALL BEARINGS, ETC.

The springs and wire were all made from carbon steel, patented and drawn, of basic electric-arc manufacture, although that detailed in Report No. 109 may have been of Swedish O.H. manufacture. The ball bearing of Reports No. 55 and 108 was made from the usual carbon-chromium steel, but those classified under Report No. 105 were rather exceptional, being 13·5% chromium with 0·4% carbon.

The quality was good in these instances, and in the majority of the minor parts.

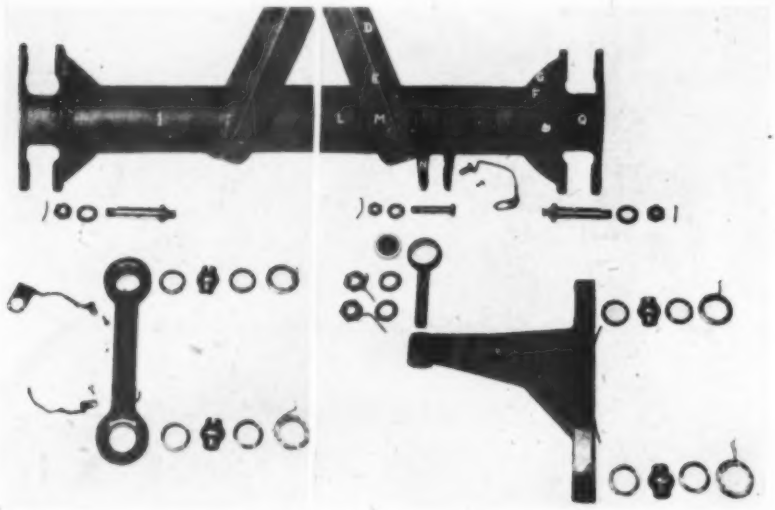


Fig. 47.—Details of tail plane incidence adjustment crank—Ju 88.

NOTICE TO READERS

The above Report, which commenced in our August, 1942, issue and has been continued in successive issues, will be completed in the March issue.

At the request of the Sub-Committee responsible for the work, and to meet the wishes of many readers, the Report is to be published in book form, and the whole of the profits from its sale will be credited to the Royal Air Force Benevolent Fund.

To ensure a substantial amount for this purpose, kindly order your copy in advance, direct from the Kennedy Press, Ltd., 21, Albion Street, Manchester, 1, and thus minimise possible waste. The price of the book will be 10s. 6d. post free.

End Quench Hardness Tests

The end-quench test is a rapid means of assessing the characteristics of steel, and is widely applied in the United States; it is used to measure the depth of hardening capacity of a steel.

A TENTATIVE method of end-quench test for hardenability of steel* has been issued by the American Society for Testing Materials. The test consists of water-quenching one end of a cylindrical test specimen 1 in. in diameter and measuring the extent of hardening from the quenched end. Depth of hardening capacity of the steel is measured by the distance along the specimen, from the quenched end, to which hardening of a given value is obtained.

A special apparatus has been designed for carrying out tests. The specimens, which are to be 1 in. in diameter and 3 in. or 4 in. long, are machined from bar previously normalised and of such a size as to permit the removal of all decarburisation in machining to 1 in. diameter. The end of the specimen to be water-quenched shall have a reasonably smooth finish, preferably produced by grinding.

Test Procedure

The specimen is to be heated, within 30-40 mins., to the temperature appropriate for hardening the steel to be tested, and is to be maintained at such a temperature for 20 mins. Precautions must be taken to protect the surface of the specimen against scaling and decarburisation. Adjustment of the water-quenching device is arranged for so that the stream of water shall be directed against the bottom face of the specimen, when supported in a vertical direction, for not less than 10 mins. As far as possible, a condition of still air shall be maintained around the specimen during cooling.

For measurement of hardness, two flat surfaces 0·015 in. in depth shall be ground 180° apart along the entire length of the specimen. Rockwell hardness measurements, on the "C" scale, at intervals of $\frac{1}{16}$ in., are made for a distance of 2 in., made from the quenched end of the specimen, along the centre line of each of these flat surfaces. The hardness determinations are to be made in accordance with the Standard Method of Test (A.S.T.M. Designation: E. 18).

Results are plotted on a standard hardenability chart, in which the ordinates represent Rockwell hardness values on the "C" scale and the abscissæ represent the distance from the quenched end of the specimen at which the hardness determinations were made. The chart also contains a scale for plotting the cooling rate in degrees Fahrenheit per second at 1,300° F., which provides a means for making direct comparisons between tests of steels using the 1 in. diameter round specimen and specimens of other sizes and shapes, as shown in the Appendix. Standard hardenability curves, plotted on such a chart, are illustrated in the original.

Hardenability of a steel may be designated by a code indicating the distance from the quenched end of the specimen within which the hardness is greater than the hardness required for obtaining an acceptable quenched and drawn structure.

Examples

In the case of a steel containing about 0·35% carbon, which hardened above Rockwell C 50 to 1½ in. (24/16 in.) from the quenched end, the index of hardenability would be expressed numerically as:—

$$J_{50} = 24 \text{ (sixteenths)}$$

A steel containing about 0·15% carbon, which hardened above Rockwell C 30 to $\frac{5}{16}$ in. from the quenched end, would be designated as having an index of hardenability of:—

$$J_{30} = 5 \text{ (sixteenths)}$$

A number of papers presented at the 1942 meeting of the American Society for Metals dealt with the end-quench test, which is being widely used as a rapid means of assessing the characteristics of "emergency" steels of new types.

* Amer. Soc. for Testing Materials: Designation A 255-42; issued 1942. Abstracted from *Nickel Bulletin*, January, 1943.

ALUMINIUM INDUSTRY

DEVELOPMENT TRENDS AND IT'S FUTURE PROSPERITY

Foreword

By W. C. Devereux, F.R.Ae.S.

TWO very eventful years have passed since I was last privileged to write the Foreword to the "Aluminium Industry" edition of METALLURGIA. At that time I forecast that unless some very intensive research was carried on to develop new processes which could utilise domestic deposits of bauxite and other aluminous ores, utilising the coal that should be available, we should be almost entirely dependent on foreign sources of raw materials to supply our vastly expanded light alloy fabricating industry, both during and after the war.

Our production of primary magnesium has greatly increased in volume and improved in quality, and employs in general, technically sounder processes than many that have been recommended for large-scale production in other countries. In addition, this country is no longer dependant on imports of magnesite. The technology of magnesium and its alloys has undergone tremendous development since 1939, and it can be confidently stated that application in industry after the war, in the field of transport, civil aircraft, the packing and textile industries, will provide employment for many thousands of workers, and exploitation of a new national asset.

In contrast to an expanding magnesium production, little has been done to provide sufficient home-produced aluminium to cope with the developments in fabrication, metallurgical knowledge, and applications that open a large potential field of national resources for post-war recovery and stabilisation.

Under the impetus of war needs, important developments have made rapid progress in our metallurgical knowledge and control of aluminium alloys, and the examination of enemy aircraft and aero-engine components, and exchange of information with our Allies, has demonstrated that the alloy developments within this country are ahead of the rest of the world. We have specialised in producing alloys for definite applications and to designers' requirements, and have developed manufacturing technique to ensure the best economy of application. Improvements in the treatment and utilisation of secondary materials, a general co-operation of the aircraft industry on metal segregation schemes, and increased knowledge of the effect of alloying elements and impurities has enabled us to use secondary grade alloys on primary aircraft structures and aero-engine components with a confidence that would have been impossible before the war.

I stressed the importance of the price of aluminium on the scale upon which it will ultimately be utilised when I wrote my previous Foreword, and still feel that this factor will probably transcend all others in determining the scope of the industry. I think it is safe to say that a notable reduction will come to pass, partly as a result of competition from secondary materials; indeed, in America, we have seen indications of this trend, where the price has already been reduced by 25% since the outbreak of war. This should by no means be the final reduction.

The results of war-time planning have seen the sudden growth of a large light alloy fabricating industry, and an even larger constructional industry employing many thousands of workers trained in handling aluminium alloy sheet, extrusions and rolled section. Welders, riveters, sheet finishers, and anodising experts are available, and we have desperate need for a long-term plan to utilise these resources, and to keep this labour in useful employment after the war.

No amount of paper planning will provide work for all these people, unless, in parallel with it, the necessary physical research is carried out. There can be no doubt that the potential field of application of aluminium and its alloys is enormous, but industrial and government co-operation is essential in planning and preparing for the future. The price will be reduced, new and efficient fabricating plants will be available, new hammers and presses will be capable of turning out parts of a size and complexity that would have been impossible in light alloys in 1939, and a vast army of workers skilled in the handling of light alloys will be fully trained and anxious for work. Unless there is ready, however, immediately after the war, a definite plan based on research which can be put in hand at once, the chance will be lost, the plants may have to be dismantled, and the workers dispersed.

In the field of transport, on land, sea, and in the air, on machine tools, packing machinery and textile machines, and as new fields in architecture and building, the possibilities are waiting, and only the organisation and control is required to keep the industry developing in the national interest.

Ventilating ducts and plumbing systems in post-war building development, pre-fabricated building units, heating equipment, doors, windows and refrigerating plant all provide suitable use of aluminium alloys in better application than alternative materials. In marine engineering and railway locomotives only the fringe of the possibilities have been touched. In the automobile industry, however, change-over to war production has gained much valuable experience in mass production of aluminium alloy pressings and plant originally intended for steel has been modified for this purpose. Their successful conquest of the difficulties involved in forming aircraft components does not, however, necessarily mean that they will continue to use these materials when they return to a peace-time market. On the contrary, they have much lee-way to make up, and may be still more convinced of the merits of mild steel over those aluminium alloys which require special heat-treatments, refrigeration storage, "springback" allowances in forming, etc., due to the fact that they have had to use alloys developed primarily for strength requirements of the aircraft designer, the production of which could be increased in war-time without technical difficulty from the days when aircraft were "hand-made" and light alloy sheet automatically signified "dural." The improvement of the present passenger or commercial vehicle meant, in the immediate pre-war period, a new body line, or another gadget. Research on applications is essential if we are not to lose the benefits of present experience, so that designers can start from the ground floor with radically altered ideas to incorporate the new methods and materials that will be available.

The industry can supply materials that are suitable for deep-drawing and pressing, that are weldable, that almost certainly will be capable of joining with high shear strength

adhesion, and can be treated to give very high resistance to corrosion, and a wide range of coloured finishes which will create new markets for the industry. Actual demonstrations, small-scale production and design research, however, on a scale not possible under present regulations and material control, are essential to convince the potential users of these materials that they will obtain to their undoubted benefit the qualities they require. There is no doubt that if this is left until after the war the impetus and experience will be lost in the effort to reproduce former output on pre-war lines, and if this should happen it will be a slow and painful task to reintroduce the use of aluminium alloys.

The planners should see to it that the necessary physical research and development is carried out on a reasonable scale *now* as an essential contribution to that which we most desire—the prosperity of our people through the useful employment of all.

Tensile Properties of Aluminium Alloys Required by Current Specifications

In Tables I to V are summarised the tensile properties required by current specifications, grouped according to form and strength. As aluminium alloys do not show a sharply defined yield-poins during test, the proof stress is determined, usually the "0·1% proof stress." This is defined at "the maximum load per square inch which, when applied to a tensile test-piece, for fifteen seconds and removed, produces a permanent extension of not more than 0·1% of the gauge length. We are indebted to the Wrought Light Alloys Development Association for the courtesy of reproducing these tables from its booklet entitled "Guide to the Properties of Wrought Aluminium Alloys;"

TABLE I.—SHEET AND STRIP.

Specification Number.	Composition (%).*								Condition of Use.	Mechanical Properties.‡			
	Cu.	Mn.	Mg.	Si.	Fe.	Ti.	Ni.	Others		0·1% Proof Stress (Tons/sq. in.).	Ultimate Tensile Strength (Tons/sq. in.).	% Elongation on 2 in.	Bend Test.
B.S.S. 3L3	3·5–4·5	0·4–0·7	0·4–0·8	0·7	0·7	0·3	—	—	Solution-treated and aged 5 days	Over 12 in.: 14·5 (Trans.) 12in. & under: 15 (Long.)	25	15	R = 3T (180°)
B.S.S. 2L38†	3·5–4·5	0·4–0·7	0·4–0·8	0·7	0·7	0·3	—	—	Solution-treated and aged 5 days	13·5	24	15	R = 3T (180°)
B.S.S. 1.47†	1·5–4·5	1·2	0·3–1·0	1·0	0·3–1·0	0·2	1·5	0·2 Cr 0·3 Ce 0·3 Cb	Softened sheet Solution-treated Solution-treated and aged 5 days	— — —	— — 25	14 12 8	R = T R = 1½T R = 3T
D.T.D. 356	3·0–4·5	1·2	1·0	1·0	1·0	—	—	—	Softened sheet Solution-treated Solution-treated and aged 5 days	— — 21	— — 27	14 14 8	R = T R = 1½T R = 3T
D.T.D. 390†	3·5–5·0	0·3–1·2	0·6–1·8	0·7	0·7	—	—	—	Solution-treated and aged 5 days	15	25	15	T < 0·104 in. R = 3T (180°)
No Specification	1·8–2·5	—	0·65–1·2	0·55–1·25	0·6–1·2	0·05–0·15	0·6–1·4	—	Solution-treated and aged	21	27	10	—
D.T.D. 182A	—	0·6	6·5–10·0	0·5	0·75	—	—	—	Annealed	—	20–23	20	T < 0·104 in. R = T (180°)
No Specification	—	0·6	6·5–10·0	0·5	0·75	—	—	—	Hard-rolled	17	25	15	—
B.S.S. L46	1·0	1·5	1·0–6·0	0·7	1·5	—	1·5	0·5 Cr	Soft	—	11	18	T < 0·104 in. (180°) (close flat)
D.T.D. 346	—	0·5–1·0	0·5–1·25	0·75–1·25	0·75	—	—	—	Soft	—	11	20	T < 0·104 in. (180°) (close flat)
No Specification	—	0·5–1·0	0·5–1·25	0·75–1·25	0·75	—	—	—	Solution-treated and artificially aged	16–22	22–25	10–16	—

* Single figures show maximum content: Remainder aluminium in each case.
† Aluminium-clad sheet. Above compositions are for bore, Minimum aluminium content of coat, 97%.
‡ Single figures are minimum requirements of the Specification. R = Radius of bend. T = Thickness of material.

TABLE II.—WIRE AND RIVETS.

Specification Number.	Composition (%).*								Condition of Use.	Ultimate Tensile Strength (Tons/sq. in.).
	Cu.	Mn.	Mg.	Si.	Fe.	Ti.	Ni.	Others.		
				1·7 Total						
B.S.S. L36	—	—	—	1·0	1·0	0·2	—	0.2	Soft	7
B.S.S. 2L37	3·5–4·5	0·4–0·7	0·4–0·8	0·7	0·7	0·3	—	—	Soft (but test figures are taken after solution treatment and natural ageing)	25
D.T.D. 303	—	0·6	4·5–5·5	0·5	0·5	—	—	—	Soft	16–21
D.T.D. 327	1·5–3·0	0·5	0·2–0·5	0·7	0·7	0·3	0·7	—	Solution-treated and aged for 5 days at normal temperature	17
D.T.D. 404	—	0·6	6·5–10·0	0·5	0·5	—	—	—	Hard-drawn	27

* Single figures show maximum content: Remainder aluminium in each case.

The Specifications should be consulted for details of the head-forming or flanging test requirements.

(*Continued on pages* 157 *and* 158.)

Some Methods for the Fabrication of Light Alloy Components

By Dr. E. G. West

Developments in the fabrication of aluminium alloy components are briefly reviewed. The processes described are in extensive use to-day and will be applied to greatly augment peace-time manufacture. Attention is confined chiefly to sheet-metal working and jointing operations, such as drop stamping, rubber pressing, stretcher pressing, and spot-welding, processes which are not new, but which have been developed rapidly during the last two or three years. The experience gained by both manufacturers and users of light metal sheet will undoubtedly facilitate its increased application to the manufacture of peace-time products.

BETWEEN the two wars a major problem of aircraft constructors was to make complicated parts as economically as the small number required would permit. When rearmament was undertaken it became necessary to produce the same parts in great quantities by unskilled labour. Thus, hand beating, spinning and other manual operations had to give way to mass-produced methods.

Large presses and similar plant with their costly dies and tools could not be justified when only a few "off" were wanted, but to-day permanent tools and high capacity equipment are the order for aircraft production, as they were in the pre-war automobile industry. A mass of invaluable experience in the working of aluminium and its alloys has been gained and as a result the light metals can be classed as readily workable where previously they were regarded as difficult materials, owing chiefly to lack of information on the technique required.

The same trend may be observed in the case of other metals—for example, the working of stainless steels or the welding of high-tensile steels—but the most impressive advances are probably in the light alloy field. It will be realised that the knowledge and experience now being accumulated must play an important part in post-war reconstruction—both physically and economically. It is, therefore, intended to summarise those processes which are being used extensively to-day and which are likely to be applied to peace-time manufacture.

The present review is confined chiefly to sheet-metal working and jointing operations, such as drop stamping, rubber pressing, stretcher pressing and spot-welding. These processes are not new, but the development which has taken place has been exceptionally rapid.

In addition to the practical experience now gained, valuable information recently published should give added impetus to the use of new methods and applications of sheet-metal forming. In particular, the fundamental discussion by Shanley[1] on the working of metals, and such papers as those by Arrowsmith,[2] Hazlett,[3] and their collaborators should enable not only more extensive fields of application to be established, but must also lead to better utilisation of the most economic field for each process.

Forming Strip, Extrusions and Tubes

Formed strip is, of course, extensively used in aircraft structures, and before the war played an important part in vehicle construction, architecture, etc. For some purposes it has a competitor in extruded sections, and it is the author's impression that formed strip is found to a greater extent in German aircraft than are extrusions.

The extrusion process itself opens up a most interesting field on account of the vast range of shapes and sizes which can be obtained at exceptionally low tool cost. War-time development in plant and technique will undoubtedly influence the post-war applications of extruded sections to a considerable degree.

Although a great many extruded sections are still manipulated and formed by hand, the skill required has, in many cases, been replaced by machine methods, using simple dies. Plant recently described consists of two dies, one on a movable head, and another operated by a pneumatic ram. The head is driven through reduction gears at a range of speeds between about 90 in. and 275 in. per min., with infinite variation.[4]

Another interesting process developed for aircraft, but with further applications, is the pipe-bending procedure of Blackburn Aircraft, Ltd. This has been fully described in the technical press, but the large saving in production-time over hand methods has not always been stressed, and it may exceed 70%.[5]

Tubes are filled with a low melting point alloy, such as "Cerrobend," and are placed in wooden dies which are able to slide over each other in grooves. The motion of the upper tool over the lower gives the desired "set," and bends in other directions can then be formed, if required, by transferring the pipe to a second set of dies. This method of precision bending in jigs enables uniformity to be maintained with unskilled labour and also allows ready checking or inspection.

Drop-stamping

Various types of drop-stamp have been used in the past, chiefly for the production of forgings, but now this plant has been adapted to the large-scale production of interchangeable sheet-metal components. The drop-stamp has developed from rope drives and friction drives to the pneumatic hammer, whilst the improvements effected by the manufacturers have been paralleled by experimental work carried out by users.

The operation of the stamp by air possesses several advantages over the gravity or friction-driven hammer, the most important being the greater speed of production obtained. The stroke is shorter than a gravity stamp for the same magnitude of blow, and the speed of the blow may be higher. Further, the return stroke can start almost instantaneously and may be completed more rapidly than by a friction mechanism; the degree of control is greater, and, if required, a gradual squeezing action can be used.

In many respects the modern drop-stamp can therefore be regarded as a mechanical panel beater, capable of producing simple or intricate shapes by one of the following methods, or a combination of these methods.

The sheet of metal (usually aluminium alloy) is placed on the lower tool (die) and a single heavy blow from the punch is sufficient for simple forms; alternatively, a series of lighter blows may be preferred, possibly followed by a heavier final blow to obtain the exact dimensions required.

The second method uses a series of plywood rings, which are used as pressure boards, to grip the edges of the sheet.

1 Shanley. *Jnl. Inst. of Aeronautical Sciences*, 1942.
2 Arrowsmith and Collaborators. *Jnl. Inst. of Metals*, 1942, p. 109.
3 Hazlett and Schroeder. *Iron Age* (especially June 18, 1942, pp. 41–46).

4 "Commercial Aviation and Aircraft Production, 4, (10), Oct., 1942, p. 82.
5 For example: *Machinery*, April 30, 1942, pp. 375–382.

The boards are shaped to clamp the outer edge of the metal and at the same time to permit the passage of the punch. After each blow, one or more of the plywood rings are withdrawn and thus the desired shape is formed in a series of "draws," a final heavy blow setting the job, when all the boards are removed. This method largely avoids the formation of wrinkles.

Often a more general squeezing action is obtained by placing one or more rubber pads between the metal and the top tool. Several pieces of rubber allow a gradual drawing action to take place, one pad being removed after each blow. Usually, a final "setting" blow is given without the interposition of rubber.

Courtesy of Alfred Herbert, Ltd.

Fig. 1.—A typical air-operated drop stamp.

Sometimes a combination of methods is used, the initial stages being by means of plywood rings, followed by rubber pad stamping to ease out wrinkles. Wrinkling is perhaps a major difficulty and, in extreme cases, it is necessary to tap out wrinkles by hand between blows. Even a combination process, including the removal of wrinkles, usually takes only as many minutes as hand working would take hours for the same article.

Simple components can be turned out by unskilled labour, but for complex forms, especially those involving draw rings or rubber pads, some experience, and possibly experiments, are necessary to determine the best sequence of blows. It is possible, however, to lay down a set of precise instructions for an operator to follow; items such as intensity of blow and length of stroke being specified. The method of control is generally very simple, and automatic control can also be devised.

Sometimes it may be necessary to anneal the article either as a whole or locally, by means of a blow-pipe flame, and, in this case, care must be taken to re-solution treat any components made from a heat-treated alloy in order to obtain maximum strength in the finished article.

Stretch Pressing

The stretching press is another machine employed especially for the rapid and cheap production of complex components, and it is likely that it will undergo further substantial development. Progress since the first machine was built in 1929 was slow until the war period, but there are now many machines in continuous use, both here and elsewhere.

The process is similar in some respects to deep drawing, but drawing in a press with a pressure plate involves compression more than stretching, and so the analogy cannot be taken too far. In the stretching press only a male die is used, the metal being formed by a hydraulic ram moving between two or more sets of clamps. The clamps grip the edges of the sheet and the general principle is shown in Fig. 3. Hydraulic pressure applied to the ram forces the tool upwards to stretch the sheet to the desired shape, which must, of course, be of a general hump-backed form. Machines now are often fitted with several rams to allow adjustment of the pipe during operation, and control is simplified by the provision of automatic stops or trips for the travel of the ram, the applied pressure, etc. Clamps may be hand or air-operated and independent adjustment of each is usually possible.

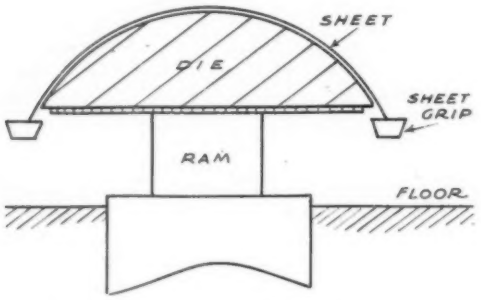
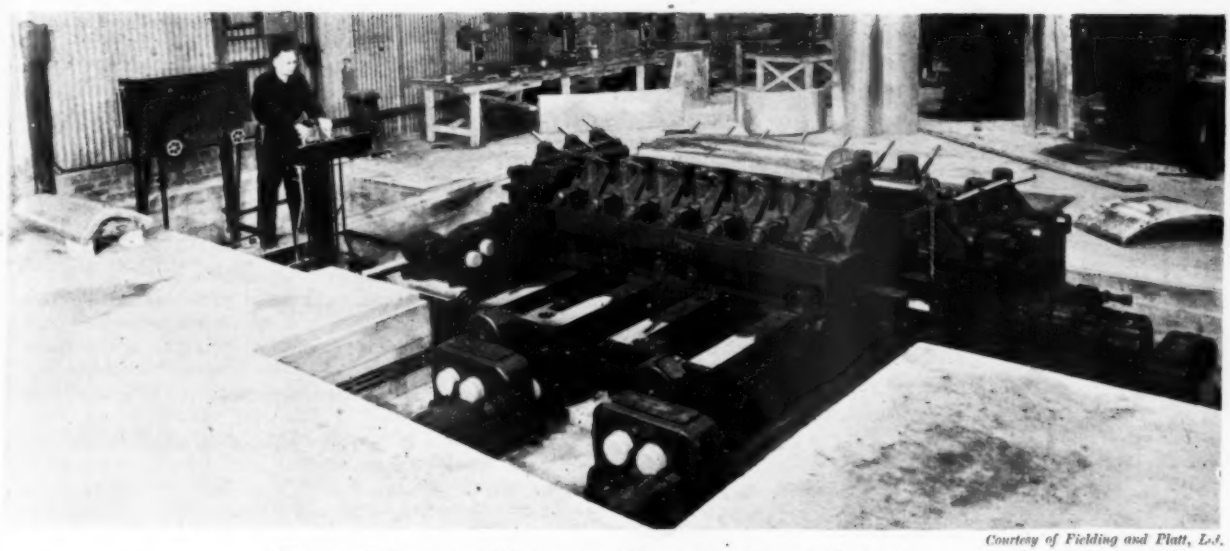


Fig. 3.—Principle of simple stretch pressing.

On the ordinary stretching press it is clearly impossible to form components recessed in the opposite direction to the motion of the tool, but the counter-pressure arrangement shown in Fig. 4 allows this type of article to be produced. A second die is situated over the ram, either held rigidly, or operated by hydraulic or pneumatic pressure, and the metal is forced into the recess in the lower tool.

The dies are usually of wood or metal, or a combination, while metal-coated reinforced concrete tools have also been used. Wood may be either natural—beech or mahogany for preference—or laminated resin-bonded material, and in each case may be covered with sheet metal, or reinforced with steel at highly stressed places. Where the quantities of pressings justify the cost, metal dies are often used, usually zinc or light alloy castings. Hollow metal tools allow heating elements to be inserted for the hot stretching of certain materials, such as magnesium-base alloys. All tools should have a good surface finish to reduce friction, and lubrication is necessary, greases, soaps and talcs being used.

It is impossible to avoid a proportion of scrap from each sheet stretched, due to the gripping arrangement, but this can be reduced to a minimum by intelligent design of the components, experience of the process, and preliminary trials to develop the most economical blank. A considerable saving in metal can often be made by forming two or more parts from one blank. Pairs of handed components are particularly convenient for such combination production.



Courtesy of Fielding and Platt, Ltd.

Fig. 2.—Recent stretching press with separately controlled rams.

Wrinkling is avoided by notching the edges, but to eliminate tearing due to stress concentration, such notches must terminate in a drilled hole. Notches are also necessary to enable sections of double curvature to be formed accurately. A well-known example is the leading edge of the "Spitfire" wing, which is some 14 ft. long and is elliptic.

It is not possible to lay down values for the amount of stretching which may be undertaken, as it is affected to some extent by the skill of the machine operator in manipulating the ram and the grippers. The amount of stretching which can be attempted in one operation is limited, and intermediate annealing or solution-treatment may be necessary. In such cases care is required to avoid the formation of areas of large grain size. According to one authority, the maximum elongation which should be attempted on "Duralumin" type alloys for parts in contact with the punch is 8–10%, while 14% may be permissible where the material is not in contact with the tool. (The specification requirement for elongation on 2 in. for this alloy is 15%.)

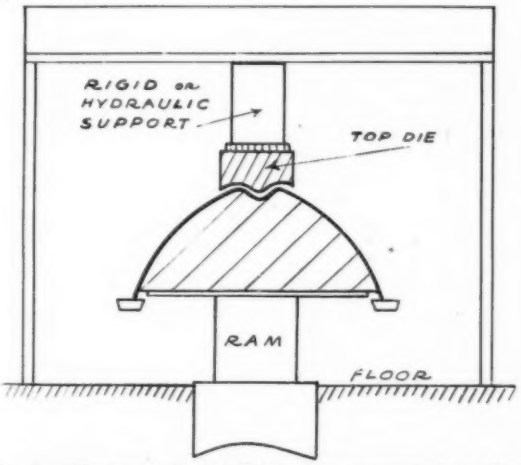


Fig. 4.—Diagram of stretching press arranged to allow recessed forms to be produced.

Preliminary rough forming, or bumping, may be required to fit the sheet approximately to the die before stretching, and some hand-beating may be necessary to finish complex shapes. The process is, however, a rapid one, capable of extension in cases where large production is required—for example, an American pressing in 0·081 in. "Duralumin" recently described required only 1¾ mins. for stretching after it was clamped in the grips.

Pressing with Rubber

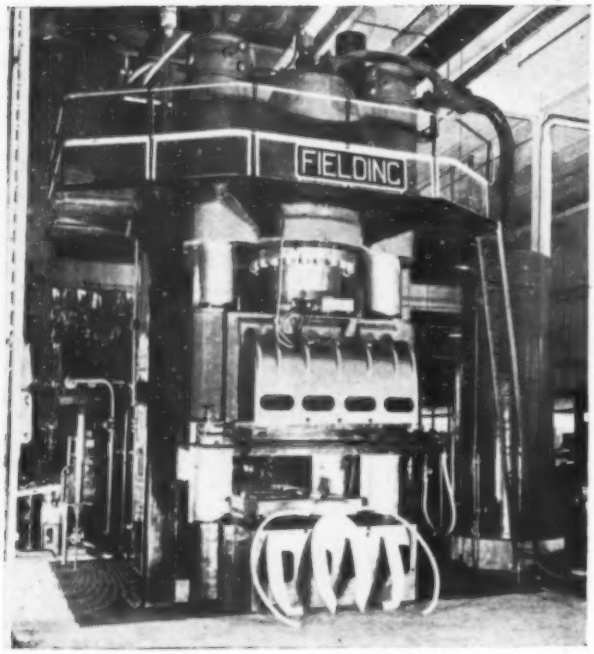
The use of rubber bolsters for production of pressings was largely neglected from its early days in 1920 until about four or five years ago, and many advances have been made recently in plant and in technique, mainly as the result of a better understanding of the fundamentals of the process. To-day there are still problems to be solved, but a great number of hydraulic presses of high capacity are in continuous production here, in U.S.A., and in Russia, some of them producing over 40,000 parts per day.

Essentially the "rubber press" consists of a steel box open at the bottom and containing a block of rubber, which is normally 4 in. to 10 in. thick. Below this rubber bolster is a table on which is placed a die, and between the rubber and the tool is interposed a sheet of metal. Hydraulic pressure then moves either the table upwards or the rubber block downwards, to force the tool into the rubber, causing the metal to form to the shape of the die. The early presses ranged up to 5,000 tons total pressure, usually with a single ram moving the rubber bolster on to a fixed table. When the demand for rubber presses increased the Ministry of Aircraft Production standardised a unit-type press, which may consist of 1, 2, 3, 4 or more units, a 4-unit plant having a total capacity of 10,600 tons on an area of 36 sq. ft. The unit construction avoids the employment of very large steel castings and allows easier handling of the component parts of the press during manufacture and erection. It is also claimed that better pressure distribution over the working area is obtained by using more than one ram. Several descriptions[6] of these presses have appeared, and a great deal of experimental work has been carried out by users, rubber suppliers, and various other organisations.

Types of Rubber.—One of the major points investigated has been the type of rubber required to give optimum results. Initially, it was considered that rubber with a Shore hardness of 50–60 was required for drawing operations, ranging to 70 for forming, and up to 80 for shearing. Subsequently, however, it has been shown that a soft rubber of 50–60 Shore hardness or lower is more suitable. This is explained on the basis of treating the rubber under pressure as a fluid—i.e., when compressed, rubber of 50 hardness gives a reading of 80 or more.

This aspect of rubber technique has been discussed in the technical press and elsewhere, but finality has not yet been reached, although the consensus of technical opinion is that soft rubber results in greater flexibility in the use of the press, and in most cases a change from hard to soft rubber has resulted in a considerable increase in production. For

6 For example: M.A.P. Directorate of Machine Tools Pamphlet, and in *Machinery*, December 4, 1941, p. 257.



Courtesy of Fielding and Platt, Ltd.

Fig. 5.—A 4,000-ton hydraulic press with a rubber pad 7ft. × 3ft. × 8 in. which has been in use for several years. The ram in this case moves downwards on the table.

example, in the pressing of fairly deep components using a hard rubber bolster, it is usually necessary to carry out the operation in several stages, making use of soft rubber "aprons" interposed between the hard rubber bolster and the metal. These aprons, which may weigh 100 lb. or more, involve an additional operation in loading and unloading the work table, but their use can be dispensed with if the rubber is sufficiently soft.

Perhaps the most important aspect of the hard versus the soft rubber controversy is in the pressure required. It will be realised that the harder the rubber the higher the pressure which must be applied in order to form metal of a given thickness and strength. Hard rubber requires from 0·75 to 1·5 tons per sq. in. for forming operations, while soft rubber is capable of producing the same parts at pressures from 0·25 to 0·5 tons per sq. in. Hence a 500-ton press with soft rubber is capable of doing the work which would require a 1,500-ton press with hard rubber.

Holding the Rubber.—The freedom with which the rubber can flow is influenced also by the method of suspending it in the container. A common method is to "bond" it to a grid-type, or perforated, back-plate, but this reduces the amount of deflection obtainable, particularly in the rubber nearest to the back-plate. A recent patent describes how the bolster is held by means of a number of nuts which are vulcanised into the rubber, the nuts corresponding with counterbored holes in the back-plate. Fixing screws pass through these holes into the nuts, thus providing a flexible attachment. Other methods under development should assist in widening the scope of the process still further.

A rough surface in contact with the metal is not harmful, and is said to reduce any risk of adhesion between the rubber and the tools, or the work. This adhesion is not usually encountered in practice because the lower surface of the rubber is normally roughened before use, and, in any case, rapidly becomes rough.

The tools may require some lubrication, but, obviously, oil or grease should not be used, and it is preferable to use either talc or graphite as a lubricant. It is important that the rubber pad should be kept free from particles of swarf, etc., which would otherwise cause scratches on the work.

Tools.—Tools are preferably designed to allow bending operations to be accomplished by external pressure rather than internal pressure. That is, the operation should be to form the metal over or round a projection rather than into a recessed hole. When using a concave tool more pressure is required than for bending round a convex die. Further, forming into a cavity may involve venting to release entrapped air.

For experimental work or for components required in only small numbers, tools may be of wood, either natural or built-up resin-bonded material. For production, however, zinc-alloy tools are normally used, although for large pressings, especially those involving any degree of deep drawing, cast iron has been adopted.

An important point in connection with tool design is the bend-radius, which must be suited to the hardness of the aluminium alloy, and it should be as regular as possible. Clearly, the edges of the die must be free from scratches, tool marks, etc., which would tend to drag or score the metal during forming.

Technique.—It is not possible to go into details of technique, as they differ according to the size of press and type of rubber, the work involved, and the experience of the tool designers and operatives. The outstanding principle which must be kept in mind is that rubber pressing cannot "lose" metal, such as is required in flanging of a convex type. Concave flanging, however, is satisfactory, as the metal is then stretched. Experience, however, allows a certain mount of "losing" to occur, chiefly by slight alterations in the design of the tool or in the exact shape and size of the blank.

The amount of spring-back often causes trouble, particularly variation in the spring-back, which requires a hand-straightening operation for its correction. With a correct technique, spring-back can be controlled within plus or minus 2°, but the amount of undercut required on the tools must be determined in specific cases. The undercut depends on the pressure available, the type of rubber, the hardness and thickness of the material, the bend-radius and its regularity, and the presence of adjacent dies on the platen. The hardness of the material is one of the major factors, for example, the undercut required for soft "Duralumin" is small, whilst the amount for the fully-aged alloy varies from 8° to 12° on a 90° bend.

Regularity of bends is assisted by using displacement or pressure-retaining blocks alongside the forming part of the tool. Often it is unnecessary to arrange separate displacement blocks as adjacent tools act in the desired manner. In general, it is found that a fully loaded table results in greater regularity of work than tables only a small part of whose area is covered by tools. In general, it does not appear that the maximum efficiency is being obtained on certain existing presses owing to the use of too few tools at a time.

More than one table is normally an advantage in obtaining not only a greater output by loading tables fully, but also greater regularity of the dimensions of the parts produced. In this country two-table presses are sometimes used, and there is at least one plant in America using six tables.[7] For deep drawing, aprons or blocks of soft rubber are interposed between the rubber bolster and the metal in many cases, while for the formation of sharp joggles, the use of very hard rubber aprons may be required. Successive drawing operations are sometimes carried out—for example, an 8-in. draw in annealed 18 G. "Duralumin" was accomplished in five stages, the first draw being 4 in. deep, the second 1⅞ in., the third 1 in., the fourth ⅞ in., and the final draw ½ in.

Blanking and piercing are operations not as suitable for the rubber press as forming, especially in the case of very small parts. The labour and tool-making involved are small, but special measures have to be taken to obtain clean-cut edges. For large components, combined blanking and forming can be carried out very economically, however, and it is for such components that the rubber press is particularly suited.

Flanging in two directions is carried out simply by using suitable tools in two stages. Occasionally, double-flanging

7 *The Machinist*, September 12, 1942, p. 519.

operations require the use of collapsible dies, but this is exceptional and can usually be avoided by alterations in design and procedure.

In this discussion of the rubber bolster press, it has been found possible only to indicate the main lines along which development is taking place, but it is considered that sufficient has been said to show the very large field which can be covered satisfactorily by this process.

Tools for Forming Operations

To-day tools for drop-stamping, for stretch-pressing, and for rubber pressing are normally white metal or soft metal castings, the basis metal usually being zinc. "Soft metal" is perhaps not quite correct, for some of the materials used for this purpose, particularly the modern zinc-aluminium alloys which have a Brinell hardness of at least 100. Such alloys are often used for blanking in mechanical presses as an alternative to the production of blanks by routing.

The "zinc" used may be either the pure metal or a zinc-base alloy such as "Kirksite" (a zinc-alloy containing aluminium is known as "Kirksite A"). Unalloyed cast zinc has a tensile strength of about 3 tons per sq. in., but the recently developed alloys give strength figures up to 16 tons per sq. in., and will withstand a maximum compressive stress of some 30 tons per sq. in.

In the drop-stamp process, the lower die only is of zinc, the punch being normally of lead. The lead used usually contains from 4–12% antimony as a hardener.

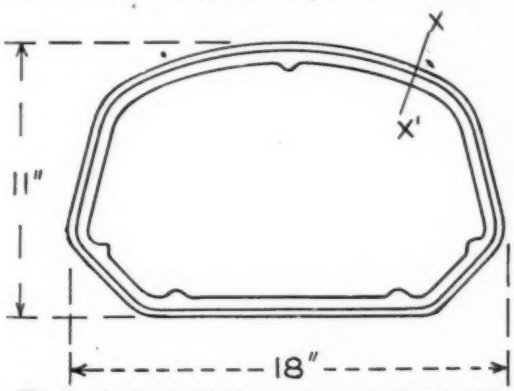


Fig. 7.—An interesting component produced with a zinc alloy tool on the drop stamp. Particular attention is directed to the thinness of the edge section on XX (reduced to ⅛ linear on reproduction).

The method of production of these white metal dies allows tools to be produced within a day or two instead of the weeks which might be required for steel tools, and the metal is readily used over and over again. A typical example is the production of a pair of tools for drop-stamping. The lower die is cast first from a plaster or wood pattern, moulded in a permeable, natural-bonded sand. The top die or punch is then cast in the lower die, the solidification shrinkage resulting in sufficient clearance for the finished metal to fit snugly in the tools. The dies are then finally shaped to size and finished with a high surface polish in order to reduce "drag" to a minimum.

These soft metals allow wood-working tools to be used, thus reducing the machining time to a negligible amount. Tool-life varies, of course, according to the method of working, but may range from a few hundred parts in severe drop-stamping operations to 10,000 or more components in less drastic operations. It is often possible to repair slight damage to these tools by some form of solder-filling, but it is usually less trouble to re-cast them, and many works now have well-equipped foundries attached to their press and stamp shops for this purpose.

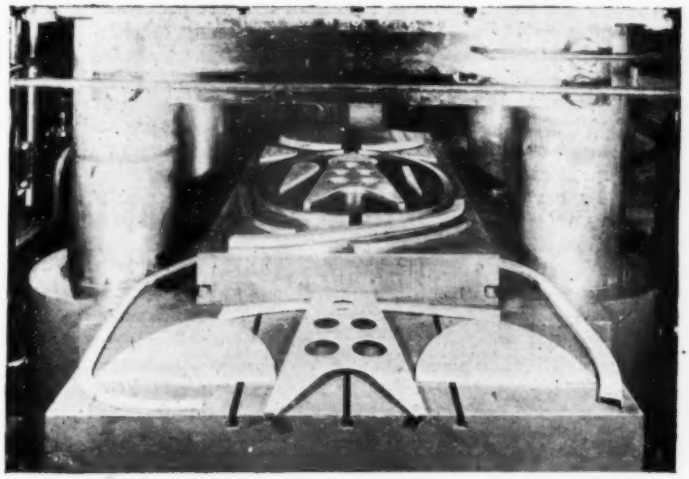


Fig. 6.—Typical tools arranged on the table of the rubber press with completed pressings shown in front.

Joining

Some of the newer developments in joining processes have not yet been fully incorporated into current production, but it is certain that these and other improvements should be available for industrial use in the near future or in the immediate post-war period.

Riveting is still the principal method used in assembling aircraft, and very high speeds are now possible on straightforward runs by automatic riveting machines. Light alloy rivet materials are of two types—namely, the age-hardening alloys and those which are not amenable to heat-treatment. Age-hardening rivets suffer from the disadvantage of requiring use within two hours of quenching, or storing at sub-zero temperatures between solution-treatment and use. This is, of course, dealt with by the proper organisation of the work in progress and also by using refrigerated containers.

A development described recently in Germany concerns an apparatus for determining the energy required to close rivets as a function of the hardness attained by them due to ageing. The device is embodied in an air-operated hammer which gives the required riveting time for standard rivets and also measures the hardness, shear strength and cold-forging properties of the metal. There are possibilities for such equipment in many applications.

Blind riveting has always been troublesome, and one of the most interesting ways of overcoming the difficulties involves the use of explosive rivets which were invented some years ago, but were not developed on any large scale until recently. These rivets are hollow, and contain a small explosive charge which is detonated by a predetermined increase in temperature. The rivets are inserted into the holes and heat applied by means of a "soldering iron," which causes the charge to explode, and in so doing expands the rivet. They are apparently used in Germany and possibly in U.S.A., but they do not appear to have made much headway in this country. There is probably not a large field for them, but they certainly possess interesting possibilities.

An item of American technique may be capable of fairly wide application, particularly in view of the unending struggle to achieve smoother surfaces for aircraft. With normal riveting methods it is impossible to prevent the development of slight irregularities, and this may entail working out special procedures to reduce wrinkling to a minimum on specific jobs. The American technique uses thermal expansion and contraction to stretch metal during the riveting operation.

8 Tarr, Darrin and Tubbs, *Industrial and Eng. Chem.*, December, 1941, p. 1575.

Close control is, of course, essential, and the procedure has been applied in particular to the fastening of skin-plating to frame structures for aircraft wings. Reduced drag is especially important in this case, and the skin panels are assembled on a jig to which is attached an electrical heating element shaped to fit the panel. Current is passed to maintain the temperature of the sheet metal at approximately 60° C., while riveting takes place, and when the current is switched off, the skin, in cooling, contracts to give a smooth surface. There are numerous possibilities in this idea, but, clearly, the conditions must be worked out and controlled very carefully for success.

Spot-welding.—Riveting is being slowly replaced by spot-welding for many unstressed parts, and, as experience is accumulated, for stressed assemblies. Spot-welding under proper conditions of control has proved itself a satisfactory process for all types of aircraft components in both heat-treated and non-heat-treated light alloys. The pure metal is less readily welded by this process than the alloys owing to its higher conductivity and small melting range.

It is now, of course, well recognised that successful spot-welding of these materials requires special machines capable of giving currents up to 50,000 amps. in the secondary circuit, combined with extremely close control of the time for which the current flows and the pressure applied to the electrode tips. It is not so well appreciated, however, that the regularity of spot-welding is more closely concerned with the surface preparation of the metal and the fit of the parts before welding than with any other factors. It is obviously necessary to clean the work before spot-welding, to remove grease, dirt, etc., but it is equally essential to remove the oxide film existing on the surface before welding. Failure to remove this film results in welds with poor strength characteristics and has undoubtedly accounted for much of the irregularity encountered in the past. Mechanical cleaning is not satisfactory, and the preferred method is to pickle the components immediately before welding in a suitable chemical solution. There are several mixtures available, and the exact procedure depends upon the solution chosen.

The working limit of machines now available appears to be the spot-welding of two thicknesses of 14 G. material, but it is, of course, possible to weld a single sheet to a relatively heavy extruded section. The ability to spot-weld thicker sheets would be of decided advantage, and the development of suitable plant is likely. In addition, further information may be expected both on the fundamentals of the process and on the design problems involved in using spot-welding, particularly for highly stressed components.

Fusion Welding.—There have been few spectacular developments in the gas and arc methods for light alloys, but some progress in the accepted processes has been made, with consequent increase in the reliability of welded light alloy components.

Oxy-gas is still the standard method for aluminium and the non-heat-treated alloys, but the age-hardening alloys must be spot-welded. New electrodes are in development for the metallic-arc process, which again is applied only to the non-heated materials. They give welds which are very satisfactory, and allow a high rate of welding to be maintained, with consequent elimination or reduction in the extent of the thermally disturbed zone alongside the weld.

Metallic-arc welding of aluminium requires direct current, but it is possible that alternating current could be used if the frequency were stepped-up considerably. The repair welding of castings, using silicon-alloy electrodes, has, of course, been practised extensively, but the development of new electrodes for wrought alloys has undoubtedly opened up new possibilities, particularly for structural work of all kinds. At present, the thinnest material which can be arc-welded is approximately 12 G., and it is likely that the gas-welding process will be used for material thinner than this for some time to come, although there are possibilities that new methods, such as the Weibel process, may become commercial propositions.

Finishing

The production of oxide finishes has steadily developed during the last 20 years, and the anodising process is now well known to all users of aluminium-base materials. The chemical and electrolytic methods for producing oxide films are employed for a wide variety of purposes to-day, the photographic process having made particular progress. It could be used in many instances in place of engraving, printing, enamelling, etc. Multi-colour anodic coatings are produced by stopping-off portions of the film while one dye is applied, followed by the colouring of the protected parts, while the first are stopped-off.

It must be realised that the type of film obtained can be closely controlled and can be varied to suit different purposes. Soft flexible coatings withstand considerable bending and other forming operations, and while drastic deformation of the metal may cause the oxide to crack, it does not show any tendency to flake-off. Films that are glass-hard can also be produced, and all types of anodic coating, of course, increase the high resistance of aluminium to corrosion. This country now possesses a large number of plants capable of dealing with components of all sizes, and combined with the considerable experience gained, should result in substantial improvements in the quality of anodised articles, and may also be expected to show lower costs. Further development will undoubtedly be called for to cope with new demands, such as *in situ* oxidation of large structures, and the treatment of large quantities of tubes and other hollow articles.

Recent American research[8] concerning the fundamentals of the chromic acid bath indicate new methods of control which are likely to prove of considerable value. There has also been further work on the development of new electrolytes for special purposes. Finally, the reflector processes must be mentioned, as they are likely to play an important part in post-war illuminating engineering.

It has been possible in this review to mention only a few aspects of light alloy manufacturing processes, and it has not been possible to include full details of any of them. There is a considerable volume of experience and information now available to users and prospective users of all the processes mentioned—indeed, one of the most valuable results of war-time practice has been the increase in the free exchange of technical information between concerns which, in peace-time, could be regarded only as rivals.

Blisters on Aluminium Forgings

BLISTERS are sometimes encountered in the forging of aluminium alloys, and in response to an inquiry, Kempf* states that there are four principal causes:—Overheating during the forging or heat-treating operation; high temperature oxidation; folds during forging; and porosity or other discontinuities in the forging stock. Overheating can generally be recognised by discolouration of the surface of the forging and a fairly general distribution of blisters over the entire surface. The remedy is, of course, more accurate of forging and heat-treating temperatures.

Aluminium alloys, particularly those containing magnesium, have been shown to be attacked by moisture and sulphur dioxide present in the furnace atmosphere during heat-treatment. This attack may result in the formation of small blisters over the entire surfaces of the forging. To avoid this, moisture and sulphur dioxide must be eliminated from the furnace atmosphere, or a special protective compound introduced into the furnace.

Although folds in the metal and porosity may cause blistering, overheating is considered to be the most common cause.

* L. W. Kempf. *Amer. Machinist*, 86, 1942 pp. 1148-50.

Investigation of the Mechanical Properties to be Expected in D.T.D.304 and D.T.D.298 Sand Castings and the Correlation of these Properties with Radiological Evidence

By L. R. Carr, M.A.
(*Radiologist, John Dale, Ltd.*)

In the past it was assumed that uniform properties in castings were not attainable, and that therefore castings were not suitable for stressed components. Latterly this position has been largely changed as a result of developments such as new alloys, improved casting technique, and the use of X-rays both for basic control of manufacturing technique and for inspection on a large scale. There is still, however, doubt and lack of knowledge as to what extent uniformity is attainable, and the question arises; What properties can be relied on in practice as a basis for design calculations? The object of the investigation described in this report is to answer this question. The results can only apply in particular to the alloys mentioned, but the conclusions are worthy of consideration as an answer to the question generally.

THE quality of components has always been of considerable significance, but in recent years increased performance demanding higher stresses with minimum weight has made it a matter of the first importance. As a result methods of controlling manufacturing technique and of testing and inspecting the finished products have been greatly developed; and in this respect the use of radiography applied to castings and welds has been outstanding. Radiography is particularly applicable to light alloys, since much finer defects can be detected in these than in the heavier metals, and when used with an understanding of its limitations it can provide a great amount of information about the strength and uniformity of components. In the author's opinion, however, if a really reliable judgment is to be formed it is absolutely essential to interpret radiographs in the light of technical knowledge of the casting process, and with constant checking of what is seen in the radiograph by metallographic examination and mechanical testing.

Object of the Investigation

An alloy specification lays down the mechanical properties which must be attained by a test bar of uniform section, cast under ideal conditions. In an actual casting, however, it is obvious that equally good properties cannot be expected throughout the casting. This at once raises the question of what properties can be relied on in practice as a basis for design calculations, and the object of this investigation is to attempt an answer to this question. Although the investigation has been limited to castings in D.T.D. 304 and D.T.D. 298, it is likely that the results would be analogous for other alloys also. It is thought, however, that the safety limit for some of these other alloys might not be such a high percentage of the specification values as for D.T.D. 304 and D.T.D. 298. The reason for this is that the specification values for D.T.D. 304, and particularly for D.T.D. 298, are easier to achieve than for some other alloys.[1] Thus, the same difference between properties of test bars and those of actual castings would mean a higher percentage difference relative to the specification than with D.T.D. 304 and D.T.D. 298.

The problem seems to involve three main lines of investigation:—

(1) The measurement of mechanical properties of sections taken from various positions in castings.

(2) The effect on mechanical properties of defects differing in kind and extent.

(3) The development of a reliable method of detecting and estimating these defects so that a safe standard of castings can be assured. This is obviously a most important aspect of the problem, since the more reliable and sensitive the method of testing the higher can be the properties of the alloy taken as the basis for design calculations. Radiological examination is clearly the most suitable method if it can satisfy the conditions of reliability and sensitivity, and this report will, therefore, attempt to correlate the mechanical properties with a radiological diagnosis of the condition of the castings.

Method of Investigation

(*a*) Each casting examined was first radiographed. Sections were then taken from various positions selected after consideration both of design and radiological evidence. Each section was then divided into two; one of these was machined into a tensile test piece, and the second polished for metallographic examination. In this way, at any selected area of a casting a direct comparison could be made between the mechanical properties and the metallographic and radiographic evidence.

The mechanical properties measured were the ultimate tensile stress and the elongation. The size of the test pieces used was limited by the wall thickness of the castings, and in all, except two cases, the cross-sectional area was $\frac{1}{40}$ sq. in. In these two cases the cross-sectional area was only $\frac{1}{80}$ sq. in. In all cases the bars were to B.S.I. proportions. The tests were carried out on a Houndsfield Tensometer, Type "C."

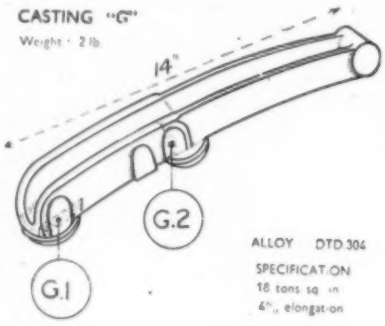
The metallographic examination was limited to macro characteristics such as grain size and porosity. These gave, at least in this instance, a sufficient explanation of the mechanical properties observed, and it was not considered necessary, in view of the type of results obtained, to interpret the properties in terms of micro structures.

The radiographic examination of all the castings was carried out according to the routine technique for each job. It should be noted that the term "porosity," unless specially qualified, means "shrinkage porosity." No special attempts were made to obtain particularly sensitive radiographs.

(*b*) *Choice of Castings.*—The essence of this investigation was to find out not so much what properties may be obtained in individual castings, but what properties can be

[1] This statement may appear surprising, but it is nevertheless a fact once the optimum casting and heat-treatment technique has been established. The following figures show the results to be expected with the specification figure in brackets, and these expected results are often exceeded:—
D.T.D. 304. 19 tons/sq. in., 5% elong. D.T.D. 298.—16 tons/sq. in., 12% elong.
(18) " (1%) " (14) " (7%) "

expected in the general run of production. In fact, a number of the castings examined would definitely have been rejected on radiography, and were chosen because of the defects they possessed. By measuring the properties of such defective sections, it was hoped to get an idea of minimum values which would be certain to be exceeded by any casting passed on radiography.



RESULTS
Casting "G" D.T.D. 304.

Radiography.—Casting appears generally sound throughout. There are signs of slight fine porosity, but the casting would be passed on radiography without question.

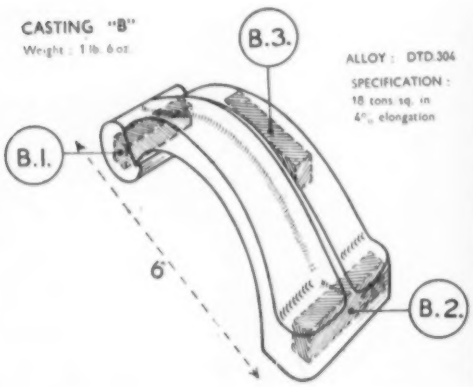
Sections.—G. 1 and G. 2 were taken as shown and the results obtained are given in Table I.

TABLE I.

Section No.	U.T.S. (Tons/in.²)	Elongation.	Comments.
G. 1	18·6	4·5 %	Section shows fine grain size and some general fine porosity. The shrinkage, however, does not tend to join up in a network.
G. 2	19·0	4·0	Radiograph shows signs of very slight porosity. Ditto

Casting "B" D.T.D. 304.

Radiography.—The radiography showed fairly fine general porosity over the whole of the middle-curved section. The thick bosses at each end showed only very slight signs of this porosity.



There were considerable blow-holes in the curved portion a little way in from the face marked with the part number.

The casting was scrapped on radiography on account of these splash cavities. It would *not* have been scrapped on account of this amount of porosity.

Sections.—Sections B. 1, B. 2, B. 3 were taken as shown. B. 3 is from the area shown by the radiograph to possess fine general porosity, while B. 1 and B. 2 are from the sounder regions in each boss. Polished sections confirm the evidence of the radiograph regarding presence and absence of porosity. B. 1 and B. 2 show only a very few isolated cavities under the microscope, whereas B. 3 shows porosity to the naked eye. The grain size of all three sections was satisfactory.

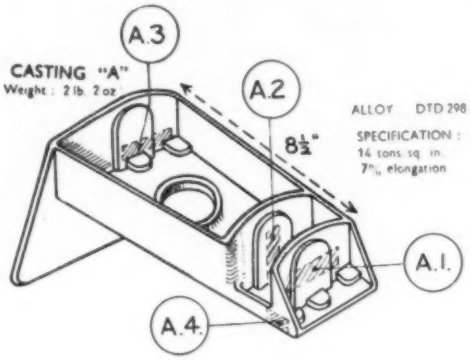
The results obtained on the three tensometer test-pieces are given in Table II.

TABLE II.

Section No.	U.T.S. (Tons/in.²)	Elongation.	Comments.
B. 1	18·0	5·0 %	Almost free from porosity in radiography and polished section.
B. 2	18·2	6·0	Ditto
B. 3	15·4	2·4	Radiograph shows general porosity. Confirmed by polished section.

Casting "A" D.TD. 304.

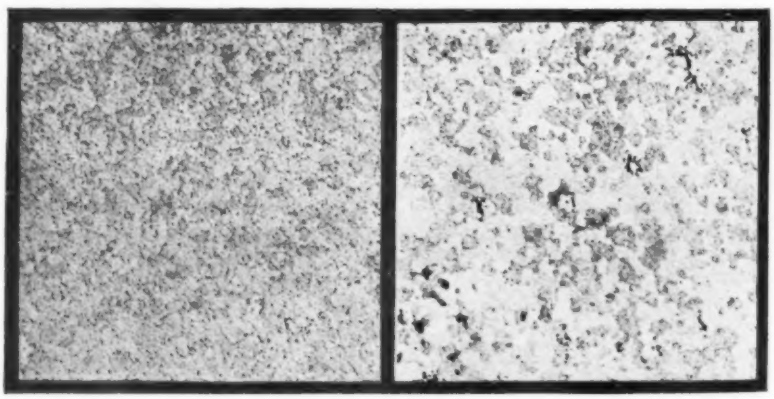
Radiography.—Severe shrinkage is shown in the two cross-members at the one end, in the base of the casting below them, and also in the side walls. The end wall with the flange shows porosity only near the top.



The porosity shown up by radiography was definitely considered sufficiently serious for this casting to be scrapped.

Sections.—Sections A. 1, A. 2, A. 3 and A. 4 were taken as shown. A. 1, A. 2 and A. 4 all come from areas shown by radiography to possess serious shrinkage.

A. 3 comes from a region of apparently sound metal.



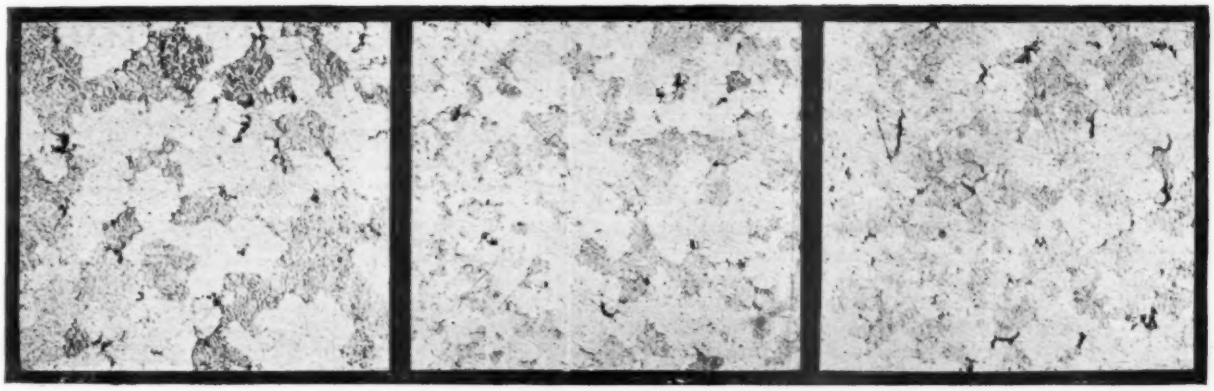
Photomicrograph* on Section B1. Note tensile test gives 18 tons/sq. in. **Photomicrograph on Section B 3. Tensile test, 15.4 tons/sq. in.**

The results obtained are given in Table III, and with each result is a comment on the radiographic and visual examination of the section.

These results are in general agreement with predictions based on the radiograph. The results for A. 1 and A. 2 are better than would have been expected from the radiograph, and the shrinkage shown on the polished sections less serious than anticipated.

The radiograph seemed to indicate similar severity of shrinkage in A. 1, A. 2 and A. 4, and yet it was only in A. 4 that this severity was realised and the tensile results correspondingly low. This raises the question whether it

* The photomicrographs reproduced with this report are of sections immediately adjacent to the tensile test-pieces bearing the same numbers. Each section was etched with 0·5% H.F. × 10.



Photomicrograph on Section A2. Tensile test, 16.8 tons/sq. in.

Photomicrograph on Section A3. Tensile test, 18.6 tons/sq. in.

Photomicrograph on Section A4. Tensile test, 14 tons/sq. in.

may have been the very large grain size in A. 1 and A. 2 shown up on the radiograph rather than porosity. This is only a tentative suggestion, however, and further investigation is required into the possibility of grain size being shown up by radiography.

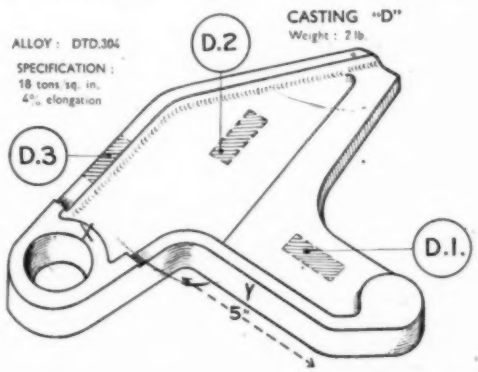
TABLE III.

Section No.	U.T.S. (Tons/in.²)	Elongation, 4%.	Comments.
		%	
A. 1	16·6	5·0	Polished section shows general shrinkage visible to the naked eye, but not as severe as expected from radiograph. This section shows very large grain size.
A. 2	16·8	5·0	Amount of shrinkage and size of grain and also appearance on radiograph very similar to A. 1. It is notable that tensile results also are nearly identical.
A. 3	18·6	7·0	Radiograph shows this section to be free from porosity, and these good results would, therefore, be expected. Polished section however, shows some general porosity although finer than A. 1 and A. 2. It is notable that grain size is considerably smaller than A. 1 and A. 2.
A. 4	14·0	2·0	Extent of porosity shown on radiograph about the same as A. 1 and A. 2. Polished section however shows more severe shrinkage—the shrinkage cavities tending to link up in a continuous network. Grain size large.

It should be noted that excellent results were obtained from A. 3, which was the one section appearing really sound on the radiograph.

Casting " D " D.T.D. 304.

Radiography.—A large cavity was shown near the bearing hole at X. In addition there was general shrinkage throughout of a fairly fine nature. This was least severe in the arm Y, and near the boss, at the end of this arm, was comparatively slight.



This casting was scrapped. Either the cavity or the porosity on its own would have been sufficient for it to be rejected.

Sections.—D. 1, D. 2 and D. 3 were taken as shown, and the results obtained are given in Table IV.

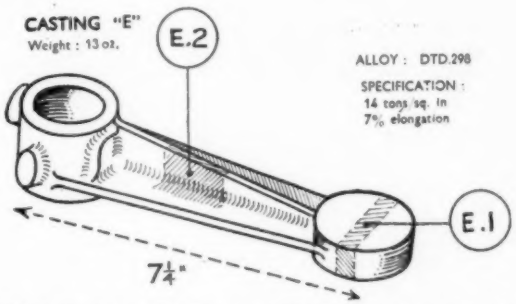
TABLE IV.

Section No.	U.T.S. (Tons/in.²)	Elongation.	Comments.
		%	
D. 1	16·0	7·0	Section shows a fine grain size and general, though very fine, porosity. Radiograph also indicates a fairly sound structure in this area.
D. 2*	13·6	4·5	Section shows a fine grain size, and very little porosity. Radiograph on the other hand, indicates considerable porosity in this area, which would lead one to expect low properties. The polished section may show a localised area free from porosity.
D. 3*	15·2	4·5	Section shows fine grain size, but considerable fine porosity. Radiograph shows very fine porosity in this area, but not severe enough at this point to expect any serious falling off in properties.

* Owing to the wall thicknesses of the casting, both D. 2 and D. 3 could only provide tensometer pieces of $\frac{1}{10}$ sq. in. in cross-section—i.e., half the area of the test pieces taken in every other case. There were no chucks available to hold such small pieces properly in the testing machine. Both pieces broke near the shoulder and also were bent, and it is likely that the apparently low values may be caused by the uneven way in which they were pulled.

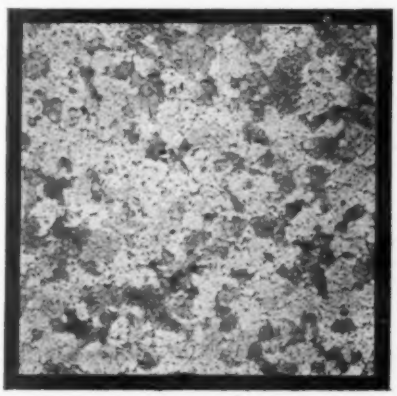
Casting " E " D.T.D. 293.

Radiography.—One or two minor cavities are shown, but the casting appears almost free from porosity, and would certainly be passed as a thoroughly sound casting on radiography.



Sections.—E. 1 and E. 2 were taken as shown, and the results obtained are given in Table V.

It is seen that both these sections which appeared really good radiographically exceed the specification values.



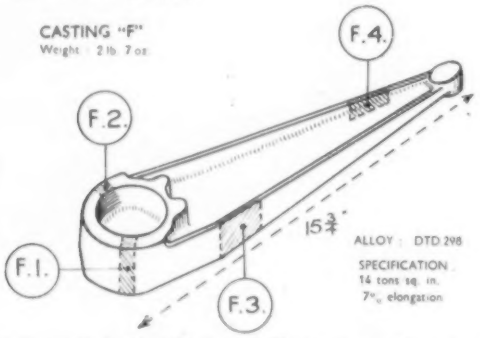
Photomicrograph on Section E1. Tensile test, 15.4 tons/sq. in.

TABLE V.

Section No.	U.T.S. (Tons/in.²)	Elongation.	Comments.
E. 1	15·4	10·5 %	Section showed a fairly fine grain size and almost complete freedom from porosity. Radiograph also indicated a sound structure at this point.
E. 2	14·6	9·8	Section showed a reasonably fine grain size and only slight porosity. Radiograph also indicated a sound structure, though not quite as good as at E. 1—an indication which is confirmed by the polished section, and also by the tensile results.

Casting "F" D T.D. 298.

Radiography.—A few small blow-holes are shown in the head and in the webs near the head, but these would be classed as minor defects. There is evidence of porosity near the edges of the thick sections of the head, and also some of a much finer character in the thin web sections. This amount of porosity, however, would not be considered as a major defect, and the casting would be passed without question on radiography.



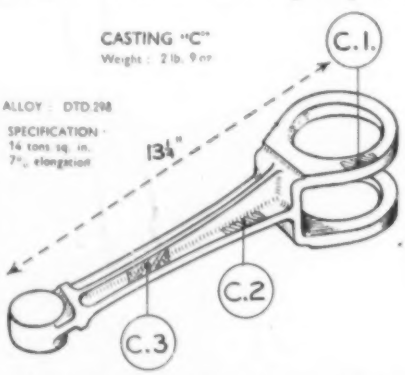
Sections.—F. 1, F. 2 F. 3 and F. 4 were taken as shown and the results obtained are given in Table VI.

TABLE VI.

Section No.	U.T.S. (Tons/in.²)	Elongation.	Comments.
F. 1	16·2	15·0 %	Section showed fine grain size and only a small amount of fine porosity. Radiograph indicates a sound structure in this region, with the exception of some porosity close to the surface of the casting.
F. 2	15·4	15·5	Ditto
F. 3	16·8	14·0	Section shows rather large grain size which is explained by the fact that it was taken immediately adjacent to a runner gate. There is some porosity, but in the nature of isolated small cavities rather than a shrinkage network. Radiograph shows a satisfactorily sound structure, but with some indication of slight porosity.
F. 4	15·8	10·5	Section shows a fairly fine grain size and only very fine porosity. Radiograph shows a sound structure.

Casting "C" D.T.D. 298.

Radiography.—The radiography indicated general porosity of a rather coarse nature—coarse enough in places to suggest the presence of sizeable cavities. This casting was scrapped on the evidence of the radiograph.



Sections.—Section C. 1, C. 2 and C. 3 were taken as shown. The results obtained are given in Table VII.

Note.—The general level of mechanical properties in this casting are in agreement with what would be expected from the radiograph. In detail, however, C. 3 seems an anomaly;

TABLE VII.

Section No.	U.T.S. (Tons/in.²)	Elongation.	Comment
C. 1	11·4	7·0 %	Polished section shows very large grain size and general fine shrinkage porosity, with one or two large cavities. Radiograph indicates unsoundness in this area.
C. 2	12·0	8·5	Section shows large grain size, although somewhat smaller than C. 1, and most severe shrinkage—a chain of large cavities runs the length of the specimen. It is surprising that the tensometer results are are so high in view of this—probably such severe shrinkage is very localised, and the tensometer bar, although immediately adjacent, was out of this area. Radiograph indicates porosity, but not nearly as severe as that actually found in the section (see note below).
C. 3	11·0	7·5	Section shows large grain size, but only very fine porosity. The radiograph also shows this area of the casting to be the only one comparatively free from porosity. It is certainly surprising that this section should have lower strength than C. 1 and C. 2.

according to both the radiograph and the polished section the results should be better than either C. 1 or C. 2.

The question arises again as with casting A as to whether the radiograph is showing up grain size, because general "blotchiness" apparently indicates much coarser porosity at C. 1 than is actually found, although the grain size here is very large. At C. 2, on the other hand, the radiograph does not indicate such severe cavitation as is actually present, and it is clear that the radiographic technique for this area was inadequate.

Summary of Results.

D.T.D. 304. SPECIFICATION: 18 tons per sq. in. 4% elongation.

Section No.	Ultimate Tensile Stress. Value Obtained.	Ultimate Tensile Stress. % of Specification.	Elongation. Value Obtained.	Elongation. % of Specification.	Radiography.
			%	%	
G. 1	18·6	101·6	4·5	112·5	Good.
2	19·0	105·8	4·0	100·0	"
B. 1	18·0	100·0	5·0	125·0	"
2	18·2	101·0	6·0	150·0	"
3	15·4	85·6	2·5	60·0	Doubtful—would probably have passed.
A. 1	16·6	92·3	5·0	125·0	Bad.
2	16·8	93·1	5·0	125·0	"
3	18·6	103·6	7·0	175·0	Good.
4	14·0	77·9	2·0	50·0	Bad.
D. 1	16·0	89·0	7·0	175·0	Fairly good—would be passed.
2*	13·6	75·6	4·5	112·5	Bad.
3*	15·2	84·4	4·5	112·5	Fairly good—would be passed.

D.T.D. 298. SPECIFICATION: 14 tons per sq. in. 7% elongation.

Section No.	Ultimate Tensile Stress. Value Obtained.	Ultimate Tensile Stress. % of Specification.	Elongation. Value Obtained.	Elongation. % of Specification.	Radiography.
			%	%	
F. 1	16·2	115·8	15·0	214·0	Good.
2	15·4	110·0	15·5	222·0	"
3	16·8	120·0	14·0	200·0	"
4	15·8	112·7	10·5	150·0	"
E. 1	15·4	110·0	10·5	150·0	"
2	14·6	102·1	10·0	140·0	"
C. 1	11·4	81·4	7·0	100·0	Bad.
2	12·0	85·7	8·5	121·5	Fairly bad—would be scrapped.
3	11·0	78·6	7·5	107·0	Ditto

* Both these results are suspect for the reason explained in the report above.

Conclusions

The results are summarised in the table attached. Each value obtained, both of ultimate tensile stress and elongation, is expressed as a percentage of the specification value. The result for each section is also accompanied by a comment on its radiography. Each comment applies to that particular section only, and does not take any account of the conditions in the rest of the casting from which it was cut. The comments do not attempt any detail. "Good" means that the section would be passed without question, and "bad" the converse. From the point of

Continued on page 154.

Aluminium in Architecture of the Future

By G. O. Taylor, M.S.E., A.I.P.E.

Aluminium and certain of its alloys are admirably suited for architectural purposes. The natural ease of working aluminium, its capability for receiving fine treatments comparable with silver, and the many attractive finishes in a large range of colours and tones obtainable by anodising, make it suitable for harmonising or contrasting with any decorative scheme. The possibilities of this material for architectural purposes were gradually being probed before the war and successfully applied for both structural and decorative purposes, and although to-day the metal is being put to sterner uses, in the future it will play a prominent part in building a new world.

IN the decade prior to the outbreak of war pure aluminium and certain of its alloys had been increasingly applied in many architectural works, but the need for putting the metal to sterner uses led to a temporary cessation of the rapid progress that was being made. The day will come, however, when aluminium and its alloys will be available for such uses in greater quantity than ever before, and the trend of modern expression in architecture towards clean white metals will be adequately met.

Intricate masses of ornamentation, conventional through tradition at the beginning of the century, have now largely been discarded in favour of the simpler form and harmonious colouration. In such decorative schemes the white metals with their neutral toning facilitate harmony, where yellow metal might be garish and discordant: and aluminium alloys, being cheaper, piece for piece, than other white metals thus start with a decided advantage. But, additionally, the lightness of aluminium, the variety of forms in which it is available, the ease of fabrication, and the divers surface finishes that can be applied to it, offer outstanding potentialities to the architect and the craftsman in metals, but however many the advantages that may be offered, metals which will not give permanence in application and retain their original appearance are of little value, and it is desirable that some general consideration should be given to the corrosion resistance of aluminium.

Pure aluminium and certain of its alloys are corrosion resistant, and can be maintained so with the minimum of attention so far as architectural applications are concerned. But it must be borne in mind that the term "aluminium" as generally applied embraces a wide variety of alloys in addition to the pure metal, just as the generic term "steel" embraces all steels from stainless to mild. With the analogy of stainless steel and mild steel in view, it is obvious, therefore, that it cannot be assumed that all alloys of aluminium are equally suited for decorative metalwork.

Courtesy of M. Aynsley and Sons, Ltd.

Metalwork of balustrade in hand-forged and polished Birmabright.

Some General Considerations

Pure aluminium possesses a resistance to atmospheric corrosion that can be equalled only by a few of the alloys specially developed for the purpose, and for purely functional applications where strength is not a factor it can be used quite successfully. The increasing tendency is, however, to use thin but strong sections which can contribute to structural strength, and many applications thus necessitate consideration of an alloy. Since many decorative schemes call for parts to be fabricated partly from the wrought forms and partly from castings, it is advantageous, in many respects, to use an alloy which can be cast or wrought with equal facility.

Basically, the wrought alloys of aluminium can be divided into two main classes: (*a*) those that can be improved in strength by heat-treatment, and (*b*) those that cannot, and which rely for their mechanical properties on the amount of working given during manufacture.

Dealing first with the alloys in Class (*a*), these are subdivisible into two categories, according to whether or not the major alloying element is copper. The heat-treatable copper-bearing alloys possess high strength after subjection to the necessary heat-treatment processes, and are largely used in aircraft manufacture. In architectural applications, however, where the metal is often exposed to the atmosphere, in the polished or other unprotected surface condition, they are not entirely suitable, as their resistance to corrosion is of an indifferent nature. If such materials are kept in a warm, dry atmosphere they remain indefinitely good, but under warm, humid conditions both indoors and outdoors, such as often obtain in this country, finished surfaces are soon rendered unsightly by a dull oxide film and roughened by pitting. This condition is greatly aggravated in the presence of sea-air.

The alloys in Class (*b*) are of more recent development than those containing copper, and rely for their heat-treatable properties on the presence of small quantities of magnesium and silicon. Unlike the copper-bearing, heat-treatable alloys, the resistance to atmospheric corrosion of this class of material is fairly high; but this advantage is somewhat offset by the need for heat-treatment to realise maximum strength.

In general, from the viewpoint of economic considerations and ease of manipulation, the alloys which possess high

strength without the necessity for recourse to heat-treatment are of primary importance to the architectural craftsman. There are a number of these alloys. The modified high-silicon content metals have long been popular for their good general resistance to corrosion, and can not only be produced in the wrought form, but can be cast into intricate shapes with facility.

In the wrought forms, however, their mechanical properties are not greatly superior to those of pure aluminium, and no particular advantage is to be derived from their use. Finished surfaces in these alloys offer considerable resistance to the pitting type of corrosion encountered with many other alloys under humid and sea-air conditions, but a polished surface quickly acquires a dull, leaden hue which cannot be described as attractive. Furthermore, these alloys are not suitable for the production of decorative finishes by the anodic process (which will be referred to later), as the surface film produced tends to be bluish-grey in appearance.

The binary aluminium-manganese alloys are poor in casting qualities, and are produced only in the wrought forms. They can be easily fabricated and have good resistance to corrosion, but they have the disadvantage that their mechanical properties are not much higher than those of the pure metal in the same forms.

The type of aluminium alloy most suitable for architectural metalwork is that containing from 2 to 9% of magnesium, with or without the addition of small quantities of other elements, such as manganese or chromium. These alloys do not need heat-treatment to produce their maximum mechanical properties, the strength being controlled by the magnesium content and the degree of working applied during fabrication. Very high-tensile strength, exceeding that of mild steel, can be obtained in certain wrought forms, with magnesium contents of 6 to 9%, but only at the expense of workability.

The alloys containing from 2 to 4% magnesium are most favoured for the types of work under consideration, since, while they are reasonably strong and approach mild steel in their mechanical properties, they are sufficiently ductile to withstand a considerable degree even of cold deformation. And it is not without importance that the 2—4% magnesium-aluminium alloys have the highest resistance to corrosion yet available in light alloy materials.

It would appear to be logical that interest should be centred mainly on the types of alloys that do not need heat-treatment, that possess high resistance to corrosion, that are capable of easy working, but which possess strength high enough to enable relatively thin sections to be used where it is necessary that decorative members should contribute also to structural strength.

Fortunately, within the last decade, the alloys of aluminium with additions of magnesium and manganese, and in some cases with small additions of chromium and silicon, have been applied commercially to a very considerable extent, and there is no doubt that these alloys do possess the somewhat superlative combination of properties, both mechanical and physical, demanded for architectural applications.

Fabrication of Light Metals

To the craftsman in metals producing intricate forms and shapes, ease of fabrication is an essential property. The problem of working is considerably reduced by the facility with which these alloys can be produced in all forms, including complicated extruded sections, thin-drawn sections, sections drawn on wood cores, thick- or thin-rolled sheets, all shapes and commercial sizes of tubing, wire, rivets, nuts and bolts, wire meshes and woven screens, while sand castings can be made for individual items or die castings for repetition production of standardised articles.

It is possible, therefore, to execute even the most complex shapes, incorporating several different forms of the metal, with the knowledge that all of the parts, being of the same chemical composition, will, in application, behave in like manner. In outdoor applications this is of importance, since all of the parts will " weather " to the same extent, and variegated effects due to differences in chemical composition and corrosion resistance will not occur.

Manipulation of extrusions, tubes, sheet, etc., does not present any particular difficulty, since the alloys can be worked in a manner very similar to that adopted for mild steel or wrought iron. Deformation can be carried out to some extent with the metal in the cold condition; but it must be borne in mind that, since the alloys rely for their strength on the amount of working applied during manufacture, they naturally become " harder " and less ductile as additional working is applied. When it is evident, therefore, that the metal is becoming intractable, it is necessary to soften it in the region of deformation, when further working can be carried out and the process repeated as may be necessary.

The temperature at which the metal becomes again tractable after cold working is about 350° C., but in the workshop this point can, with a little experience, easily be gauged by the simple expedient of heating with a blow-lamp flame until when a matchstick is rubbed on the hot metal it just leaves a brown char mark behind.

Many tube manipulations can be carried out cold with a tube-bending machine, but where very acute bends may be necessary on relatively thin-walled tube, it is necessary to support the metal against collapse on the inside radius of the bend by filling the tube with a fusible alloy such as " Cerrobend," which is subsequently easily melted out of the completed work.

All the normal machining operations can be carried out with ease, due to the free-cutting properties of the aluminium-magnesium alloys. Some slight alterations in tool design are sometimes necessary, but these are adequately dealt with in various publications issued by the producers of the metals.

Torch welding by the oxy-acetylene or oxy-hydrogen processes presents no particular difficulty, and once the technique has been acquired it will be found that the metals are, in fact, readily weldable. Careful adjustment of the flame to a neutral condition gives the soundest welds at maximum speed. Since all aluminium is coated with a thin film of oxide, which tends to prevent molten surfaces from coalescing together, it is necessary to use a flux of which there are several proprietary brands readily available.

In architectural work, it is of particular importance that the welding rod used should be of the same composition as the pieces to be joined, otherwise if a welded joint is subsequently polished and left to weather, a distinct difference in colour will be evident at the weld. This difference will be even more marked if a welded assembly is anodised, and the colour difference will be so marked as to be conspicuous. For instance, if aluminium-magnesium alloys are welded, using the popular 5% silicon-aluminium alloy welding rod, the anodised assembly will show an irregular blue-black band against a frosty silver background at the area of welding.

The weld metal is deposited with a chill-cast grain structure, and when wrought parts are welded and subsequently anodised, even if the same composition of welding rod is used, the area of deposited metal sometimes shows up with a crystalline structure due to the slight etching brought about in the anodising process. Wherever possible, therefore, all welding should be carried out with the work chamfered from the back to the front of the assembly, so that at the front or visible surface only a minimum of deposited metal is evident. With joints made in this manner, there is practically no evidence of differences in colour or grain size at the weld in the finished job.

For certain types of architectural work mechanically strong joints can also be made by soldering; although it should be borne in mind that soldered parts are likely to

prove unsatisfactory in any application where humid conditions might be encountered, due to the possibility of electrolytic corrosion arising at the joint.

The soldering of aluminium alloy demands a special technique and special solders. Owing to the presence of the invisible film of oxide, light metal surfaces cannot be "wetted" with solder in the same manner as can copper or brass, and it is necessary to cause the solder to adhere by mechanical disruption of the oxide film while it is under a coating of the molten solder.

This can be achieved by means of brushing the molten solder "into" the metal with a wire brush or pad of steel wool. When opposing surfaces are coated in this manner they can be heated to just above the melting point of the solder, further solder added if necessary, and then pressed together. Joints made in this manner have a tensile strength of about 3 tons per square inch, and are relatively permanent if kept dry.

The ordinary tin-lead solders are not used with aluminium, since it has been found that they do not readily "tin" the metal. Several proprietary brands of aluminium solder are available, but it can be indicated that the best results are obtained either with solders containing tin and zinc, or zinc and cadmium, or with zinc alone.

With proper appreciation of how, where and when they should, or should not, be used, solders of this type can be very useful; but unless the joints can be suitably protected with paint or other medium, they are not recommended for outdoor use. It is also not advisable to use this method of jointing for parts which are subsequently to be finished by the anodic oxidation process.

Surface Finishes

The variety of surface finishes that can be applied to pure aluminium and the aluminium-magnesium alloys is greater than is possible with any other metal used in architecture. They can be generally classified under one of the headings—(*a*) mechanical, or (*b*) electro-chemical.

The most popular mechanical finish is that given in the polishing operation. Light metals can be polished with standard equipment, but since the metal is "softer" than steel or brass it is necessary to use slower wheel speeds, finer abrasives, and liberal lubrication. Under normal dry interior conditions the polish is well retained on most aluminium alloys, and an occasional rubbing down with a soft rag is the only maintenance attention required.

Where, as in many interior applications, the atmosphere tends to be warm but humid, then the superior qualities of the special aluminium-magnesium alloys are evident, since they require far less maintenance attention than other alloys to retain the polished surface in its original condition. Even if neglected for months at a time until the surface has become dulled by the formation of an oxide "bloom," this can be removed with ease in a few moments by rubbing with a soft cloth. In a few cases it may be necessary to use a little plate-polish, but it will be found that the original brightness can be restored with far less effort than is necessary with most other polished metals.

It is of importance that where polished metalwork is continually handled, as in the case of door furniture and handrails, the aluminium-magnesium alloys are immune from tarnishing, due to the presence of uric acid in perspiration; although such tarnishing does occur with many aluminium alloys of other types.

The permanence of polished light alloys out-of-doors depends largely on the situation. In rural districts a polished shop-front, for instance, would require only an occasional wiping down to preserve it in good condition; but in an industrial area the gases discharged into the atmosphere render it necessary to give fairly regular maintenance attention to all polished metals. Even stainless steel, if neglected under such conditions, acquires a film of dirt and oxide.

Courtesy of the "Architect and Building News."

Metalwork of counter, counter-screens, grilles to counter and windows and balustrades in polished Birmabright.

Therefore, in such applications, it is necessary in common with other metals to rub down light alloy polished surfaces, and occasionally to apply a little metal polish to remove oxide bloom. But it is under such conditions that the outstanding properties of the aluminium-magnesium alloys are revealed to the best effect. A polished surface in such an alloy can be completely restored with a little metal polish, even if left untouched for a year; but under the same conditions a polished surface in a copper-bearing alloy becomes rough and pitted, while the polished surface of a silicon bearing alloy acquires a dull, leaden hue which cannot easily be removed.

In addition to the polished finish which has been discussed at some length, since it is so popular, there are several other types of mechanical finishes which can be utilised with excellent effect. A pleasing, non-reflective soft-burnished effect, for instance, is produced by very fine grinding of the metal in one direction only, or by rubbing down the polished surface with a fine abrasive such as pumice powder. For panelling, large sheets can be obtained with a finish known as "satin," obtained by machine treatment with rapidly revolving fine wire brushes. Such finishes, being non-reflective, do not show bloom as a polished surface may in some conditions, and can be applied with advantage in many schemes where a bright surface might appear garish.

Sandblasting can be used with good effect in the production of designs on panels, the metal first being polished, or satin-finished, and the design cut from thick paper and glued to the surface. On lightly sandblasting and then soaking off the paper, a polished or satin pattern is prominent against a non-reflective matt and slightly roughened background. Sandblast finishes are not suitable for outdoor use, however, unless the metal is afterwards treated by the anodic oxidation process, since the roughened surface easily picks up dirt and stains and cleaning is difficult in the absence of the hard wear-resisting skin conferred by "anodising."

Intricate pattern effects can also be produced on sheets by the use of patterned rolls during process of manufacture, and a development which should find substantial outlet is the possibility of producing any type of figured sheet by the use of paper or parchment patterns which can be more easily produced than engraved metal rolls. The variety of effects available is greatly extended by the combination of mechanical finishes with electro-chemical finishes. The electro-chemical process of anodic oxidation has superseded

all purely chemical immersion processes for the production of decorative surface coatings for architectural metalwork.

The natural high-corrosion resistance of pure aluminium is due entirely to the presence on the surface of a minutely thin and invisible film of oxide, which instantly reforms if the surface is abraded. In the anodic oxidation process this natural oxide skin is artificially built up to visible and measurable thickness by making the metal the anode in an acid solution. On the passage of a direct current nascent oxygen is liberated at the metal surface, and at once combines with it to form a hard dense skin which is integrally bonded to the metal and cannot peel or flake off. Several different types of acid solution can be used, but in this country developments for decorative finishes has centred mainly around the use of sulphuric-acid electrolytes of various types and concentrations.

By manipulation of the process factors of time, temperature of electrolyte, concentration of acid and applied voltage, the film can be built up with varying physical characteristics. For instance, it can be intensely hard, brittle and resistant to abrasion, or it can be relatively soft and capable of deformation without visible effect.

The avenues for decorative schemes opened up by anodic oxidation are many and varied; particularly when it is realised that since the anodic film is a natural mordant for dyestuffs, it can, by immersion in suitable dye solutions, be permanently coloured in a wide range of opaque or translucent tints. Furthermore, since the oxide coating is minutely porous, it is also possible to precipitate mineral pigments such as, for instance, Prussian blue, inside the film itself, to give a further type of coloured finish additional to that achieved with dyestuffs. Lastly, the oxide film can be "sealed" by certain treatments, so that the film, instead of being porous and readily stainable, becomes virtually stainless and waterproof. The value of this is evident in applications such as door furniture, table-tops, metal furniture and the like.

By variation of process factors and preparatory finish given to the metal surface, the anodic oxidation process, therefore, provides a wide range of stainless, wear-resistant finishes, ranging through natural colours, such as frosted silver, silver matt, and antique silver, to all the myriad colours that can be obtained by dyestuff combinations. By masking, etching and stencilling processes, multi-colour, printed or patterned designs can be reproduced, so that the decorative possibilities are virtually unlimited.

Since the high-corrosion resistance of pure aluminium and the corrosion-resisting alloys depends on the property of acquiring a minutely thin but protective oxide film, it is obvious that the artificial thickening of the film into a coating still further increases the resistance to corrosion in proportion to the degree of resistance possessed by the specific alloy in the natural state.

Under interior conditions anodised finishes will retain their original condition indefinitely with no attention other than an occasional removal of deposited dirt. For exposure to industrial atmospheres, their passivity is such that if they are washed down twice a year and "polished" with a small amount of floor polish or grease they will far outlast most other metal finishes.

Coloured anodised finishes exposed indoors remain indefinitely good, but the range of colours fast to sunlight and weather for exterior uses is more restricted; but research by the specialists in this process has resulted in the advancement of the art to an extent where they can offer certain colours proof against fading or leaching.

The Uses of Aluminium in Architecture

The uses of light metals in architecture of the future will undoubtedly be many and varied, both for structural and decorative purposes, and it is of interest to review some of the applications to which they were put in the period of development prior to 1939, both in this country and abroad.

In American sky-scraper buildings, cast aluminium alloy spandrels were extensively used, both as a means of ornamentation and also to reduce superstructural weight to lessen pressure on the foundations. The confidence of the architects in the suitability of light metals is reflected in the fact that the Empire State Building contains some 380 tons of aluminium in the form of spandrels and other applications; while in the Rockefeller Centre Building over 700,000 sq. ft. of the building exterior is faced with decorative cast aluminium spandrels, weighing in total more than 1,340 tons.

That this confidence in the ability of properly chosen aluminium alloys to give permanence in application is justified is substantiated by the examination made of the cast aluminium cap stone of the 555-ft. high Washington Memorial after it had been undisturbed for over 50 years. Although this cast cap stone was made when aluminium was regarded as a semi-precious metal, the only corrosive action observed when the natural oxide film was removed was an isolated pitting less than $\frac{1}{1000}$ in. deep.

Cast aluminium alloy facings of the type discussed have the important advantage that since the corrosion products of aluminium are colourless, surrounding stonework can never become stained and discoloured, as is often noted with ornamental facings in other metals.

Another application in which considerable development is likely is in the application of the corrosion-resisting alloys to cast statuary work and monuments. Perhaps the largest work of this type yet completed is a naval memorial erected in the United States. Made entirely from castings anodised and coloured by the sulphuric-acid process, this monument of seagulls flying over the crest of a breaking wave is over 30 ft. high. Another typical example is the statue of Saint Christopher by the Italian architect, Mazzoni. This statue, although 11 ft. 6 in. high, was cast with a wall thickness of only $\frac{3}{16}$ in., and weighs but slightly more than 3 cwts.

In this country the statue of "Eros," in Piccadilly Circus, erected in 1893, is a casting in aluminium alloy; but many applications of light metals have been made in architectural work during the last ten years and it is not posisble more than briefly to review these as an indication of how light metals have been and will be used in the future.

One of the finest examples of the use of anodised and coloured metal is in the escalator casings at Messrs. Harrods, Ltd., Knightsbridge, built up from extrusions and "imprest" patterned sheet panelling, anodised in two shades, coral and silver. In Fleet Street the *Daily Express* building has a façade of black glass with cover strips of aluminium alloy anodised to a silver finish. The observation lounge and cocktail bar of R.M.S. *Queen Mary* is a magnificent example of the use of wrought and cast materials in the highly polished conditions for balustrading. Material anodised to a silver finish has been extensively used in the Gerrard Street, London, Post Office and Telephone Exchange for doors, window framing, panels, spandrels, telephone boxes, grilles and several other items. At Arlington House, St. James's, London, is a typical example of the use of anodised light metal in a residential building. The window-frames have anodised surrounds and there are shop fronts, doors, grilles, railings and balcony surrounds all in the same metal.

It is possible to point to a very considerable number of such major applications, in addition to an even greater number of minor uses, but the examples quoted and illustrated are sufficient to indicate the confidence felt in the future of aluminium in architecture.

The developments which have taken place in this direction are not widely known, but without doubt the tendency to depart from the conventional materials and work along newer and bolder lines with light metals was but the indication of the "shape of things to come," and the knowledge in practical applications gained in the past will play a prominent part in the building of our new world.

Rationalisation in Iron Foundries

Part II.—Application of Principles

By F. L. Meyenberg, M.I.Mech.E.

Applied in the direction of co-ordinating effort, organisation is the first step towards industrial planning; this in turn is the precursor of systematic production. Experience has shown that improved efficiency in industrial work can be effected by rationalisation, and in the first part of his report on this subject the author discussed general principles of rationalisation; in the present part he deals with the application of these principles to iron foundries.

THE subject under discussion is not new, for much has been done in the past to improve efficiency in industrial works by rationalisation, but in the change from war to peace conditions reorganisation of industry will present a special problem, and the need for rationalisation will increasingly manifest itself. In the last issue consideration was given to principles which may be applied to industry generally. In order that the subject may be considered in some detail, the present part is concerned with the application of these principles in the specific case of iron foundries. It is proposed to discuss this under three main sections—organisation studies, time studies, and costing studies.

ORGANISATION STUDIES

Before any rationalisation work can be started, it is useful to find out which stage of organisation exists in the works under discussion. The following table may help in forming an opinion in this direction by giving the four main stages, which can be distinguished, and their characteristics as to administration, clerical work and workshop practice.

The fact that these stages are indicated by the figures I, II, III and IV does not mean that in a practical case a lower stage must be inferior to the higher in all circumstances; on the contrary, it may be that it would be a great mistake to change from such a lower stage to the higher. That depends entirely on the special conditions, the extent of the works, the nature of its products, whether jobbing work, series- or mass-production, whether situated near a town or in the country, the character of the population, etc. It must be left to the responsible person whether a change to another stage would be advisable as soon as the first investigation has left no doubt about the momentary state of organisation. But if a change has been decided upon, it must not be overlooked that a success can be obtained only if this development is carefully planned and prepared, especially by discussing it with all concerned, and then the introduction of the new organisation must be carried out carefully, step by step, not doing the second, or even the third, step before the first could be regarded as finished and actually settled.

The writer remembers various examples where this obvious rule had not been observed, and a favourable result could not be obtained for years in spite of much work spent on this problem. Furthermore, the fact that the above table gives only four stages does not mean that no intermediate stages are possible. The practice shows the contrary in a great number of variations. The table should not be anything but a support for judgment of the state of organisation one may discover by the first investigation, and a basis for the decision of further development.

But before leaving this table of the various stages of organisation one fact should be mentioned which has often brought, and still brings, trouble when the transition from a lower to a higher stage has been decided upon, i.e., the increase of the number of staff members in proportion to the number of workmen. Possibly this increase is permitted for the time of transition; but when that is over, it is asked that the old proportion should at least be restored. A simple consideration shows that this demand is nonsensical. What has actually happened by this transition is that work, which has been done by workmen, chargehands or foremen, has been taken away from these people and put to specially trained members of the staff, clerks, planning or time-study engineers, etc., who will do this work quicker and better, leaving to workmen, chargehands and foremen more time for their special job. Thus, the output may be increased or the quality improved, but

VARIOUS STAGES OF ORGANISATION.

Stage.	Administration.	Clerical Work.	Workshop Practice.
I. A mechanic's shop.	Only first beginning of administrative activity.	No printed forms. All clerical work is contrived each time from the start. The success depends solely on the ability and conscientiousness of the executive. Dates of delivery made by guessing.	The workman has himself to fetch all he needs for his work; he works according to his own discretion. Assistants for production work very rare. Almost no piece-work wages.
II. Shop managed completely by a foreman.	Principles, as well as details left completely to the personal opinion of the executive.	Printing forms for the main work. Nevertheless, all is left to the personal opinion, conscientiousness and ability of the executives. Thus, executives are "indispensable" as substitutes need long time to become familiar with the work. No statistics. No control of delivery dates.	Some assistants for production work are at hand; nevertheless, specialists have to carry out "unproductive work" for many hours. The more experienced workmen can do the work as they think best. Partly piece-work wages.
III. Some tendency to planning the management (a very usual stage).	Principles are strictly ordered by the manager. Details are partly left to the executives.	Well-developed printed forms for all work. The quality of the work is no longer completely dependent on the ability of the executives. There is a tendency to systematic control by the use of the printed forms. Statistics give a good survey. Control of delivery dates by the manager.	"Unproductive work" is taken from the specialists to a great extent. Distribution of the work by the manager and foreman respectively. There is a tendency to actual planning of the work. Piece-work wages where possible. Some piece-work prices are based on time studies.
IV. Planned management carried through completely (a stage at present still fairly rare).	Planned and ordered up to all details. Only partly dependent on the personality of the manager, as directed from a planning department that may be outside his influence.	For all clerical work printed forms exist, the application of which does not put great demands on the intelligence of the clerks. Strict and automatic control. Complete statistics carefully carried out and referring also to costs. Control and anticipating disposal of delivery dates. Detailed statement of economical success at the end of each month.	The specialist is discharged of all "unproductive work." The distribution of the work is carried out according to plan. Working methods are systematically investigated with regard to the possibility of improvements. Fair piece-work wages are used based on time studies

also the total number of persons employed has gone up since the staff has more work to do than before.

The result of this kind of rationalisation is that the ratio characterised before $\frac{\text{number of staff members}}{\text{number of workmen.}}$ has increased. And this increase may be considerable. Cases are known where it went up from $\frac{1}{10}$ to $\frac{1}{8}$, or even more. But what does that matter if, at the same time, the profit of the undertaking increases, or even the costs per unit of product decrease? This development should not only be welcomed by the management of the concern in question, but also by the employees and the public generally, as it ultimately means that more people are set free from manual labour and occupied with mental work.

When further following up the assumed organisation study, the next step will be the preparation of an organisation plan of the departments of the works showing their various functions and positions with regard to each other. No examples are given here as so many are available in the handbooks of industrial administration that they would be regarded as superfluous. Moreover, each concern has its peculiarities which should be considered as of special importance when developing this first organisation plan into a true copy of the actual conditions in the works. Whether these peculiarities are justified or not is another question, which may be the next object of consideration. Generally, it can only be said that they should not be removed, if the advantage of this measure is not quite obvious. In every industrial undertaking, with a previous development of some years, there is a kind of tradition which is mostly an asset in itself, and which gives to the concern a certain stability. This should not be touched unless absolutely necessary. As for the rest, reference may be made to what has been previously mentioned in the first part of this report with regard to organisation studies.

Time Studies

The discussion under this heading is partly based on investigations and publications made jointly by the "Verein Deutscher Eisen-giessereien" (Association of German Iron-Foundries) and by the "Reichsausschufs für Arbeits-studien" (German Institute of Work and Time Studies), for which the writer was partly responsible at that time. It may first be stated that the term "time studies" is used throughout for investigations, which could be termed either "work studies" or "time studies proper" or "motion studies." In any case, it should be understood that the expression "time and motion studies," probably originating from American sources, does not include "work studies," which are the most important part of the total investigation. Usually, the work studies must precede and accompany the time studies proper, while the motion studies, also combined with time studies, are a refinement of the investigation that will be necessary, or are commendable only in some cases, e.g., when machine moulding in the mass-production is investigated.

It is not claimed that the ideas and principles behind these investigations are new. They are known throughout the world, and certainly used in practice in many countries, including this country. But the form of these investigations, as presented below, is the result of very thorough considerations of the two corporations previously mentioned, and is accepted by the German industry as a kind of standard. Its adaptation to British industrial works has proved valuable, and if the British iron foundry industry could be convinced as a body that this or a similar form of systematic investigation could be applied, the result would doubtless be the same, especially the understanding between the various members of the industry, the interchangeability of experience and the familiarity with new conditions, when changing positions from one company to the other, would be much easier, and certainly beneficial to the industry as a whole.

Perhaps some readers will regard these last viewpoints as a disadvantage to individual works. Experience has shown, however, that this opinion is definitely erroneous. It should not be overlooked that these are not secret methods, like metallurgical processes developed in a laboratory and applied to practice, but generally known ideas brought into a certain system and adapted to the working conditions varying from one works to the other.

Analysis of Work

When analysing a special job, e.g., producing a pulley on a moulding machine of the box-lift type, a working plan has to be made, built up from processes, operations, motions and unit of motions.

A *process* is a complete series of operations for the purpose of production, performed by one worker, or a group of workers co-operating, at one working place.

An *operation* is the next smaller unit, or a stage in a process of production carried out at one working place.

A *motion* is a compound group of actions of the worker in the course of production, or preparation for production, consisting of several units of motion. Sometimes several motions may be treated as one motion for simplification of calculation, and this is called a motion group.

A *unit of motion* is the smallest observable or measureable action of a worker in the course of production or preparation of production, consisting of a single complete movement.

As these definitions—necessary as they are for the understanding of what is meant by analysis of work when applied to jobs in practice—may produce a somewhat academic impression, it may be useful to give an example, such as that in Table I, which is taken from actual practice. It should be added, however, that this form of analysing to the smallest details will not always be necessary or even commendable. It depends entirely on the nature of the

TABLE I.—WORKING PLAN OF A PULLEY.
(MACHINE MOULDING AT A FLASK LIFT MACHINE.)
(° MEANS THE PROCESS IS NOT FOLLOWED UP FURTHER.)

Process.	Operation.	Motion.	Unit of Motion.
Moulding.	Producing the drag.° Fixing the cores.° Producing the cope → Covering.°‡	Setting up the cope → Powdering.° Riddling facing sand.° Setting gate pattern.° Pressing on the sand ° Shovelling in backing sand. → Preliminary ramming.° Refilling backing sand.°	→ Movement from machine to pile of flasks. Taking up the cope. Lifting the cope. Carrying the cope to the machine. Putting the cope on the machine. → → Movement from the machine to the shovel. Taking up the shovel. Driving the shovel in the sand (repeatedly). Filling sand into the cope (repeatedly). Putting aside the shovel.
Core-making.	Ramming the core of the bore.° Baking (baking proper and manipulating).° Blacking.° Reb king (baking proper and manipulating).°	Ramming. → Striking off.° Venting by piercing the rammed sand.° Taking out the gate pattern.° Making the pouring basin.° Rapping and lifting off.°	→
Casting.°		Finishing the pouring basin.° Putting aside (covering).° Dusting off the pattern plate and moving down the pins.°	→ Taking up the rammer. Lifting the rammer (repeatedly). Pushing down the rammer (repeatedly). Putting aside the rammer.
Knocking-out.	Knocking out the casting → Transport to the dressing room.° Working up heap sand.° Finishing moulding floor.°	Knocking out the cope → Packing out the casting.° Knocking out the drag.° Tapping the casting and knocking off the gate.° Putting together the castings.° Piling the flasks.°	→ Taking up the hammer. Rapping the sand. Putting aside the hammer. Taking hold of the cope. Lifting the cope. Cleaning the cope from the sand. Putting aside the cope.
Cleaning and Dressing.°			→

work in question—whether hand or machine moulding, whether single, series or mass production, etc., how far it is advisable to go into these details.

Even the five processes shown in the example are sometimes not separated in such an accurate manner, the division of labour not being driven to its last consequencies in the foundry in question. In this connection it is possible to distinguish the five cases :—

1. All five processes are strictly separated.
2. Moulding and casting are comprehended and done by the same group of men, perhaps against a common piece-work price ; core-making, knocking-out and cleaning and dressing are separated actions against separated piece-work prices.

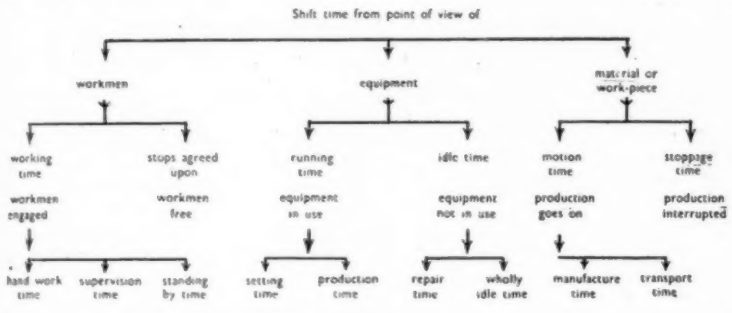


Fig. 1.—Analysis of shift time.

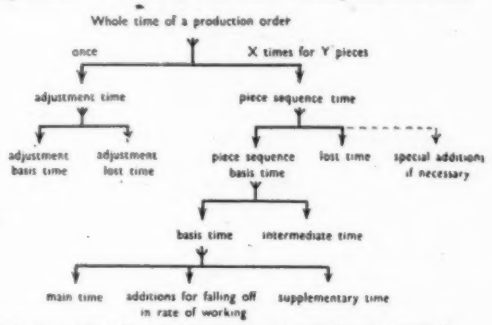


Fig. 3.—Detailed analysis of "working time."

3. Moulding, casting and knocking-out are considered as closely belonging to one another, and only core-making on the one hand and cleaning and dressing on the other hand are separated. This is a case still often encountered in practice.
4. Only cleaning and dressing are separated.
5. All five processes are comprehended and paid by one piece-work price.

(Theoretically, it is possible to consider cleaning and dressing as two different processes, and this may perhaps be helpful in some cases for costing purposes ; but the writer does not remember a single case in practice where the division of labour was driven so far that these two actions were carried out by two different groups of men, therefore the division into five cases, and not into six, is chosen in the example as the largest possible division of labour.)

Analysis of Time

The introduction of time as a measure into the workshops, instead of money, is still so much in dispute in practice that it may not be superfluous to give some remarks on this question in advance of the discussion of time analysis.

If the duration of a job must be anticipated, say for planning purposes, etc., it is clear that time is the correct basis ; but if an agreement on payment to the men for this job is in question, time can be easier understood, since then the earnings per hour are not under discussion, also the comparison of the times stipulated in advance and actually used is very simple. Experience has shown that the use of time instead of money has a calming influence in all shop affairs, and should therefore be applied as far as it can possibly be done. Of course the conversion from time to money cannot be avoided ultimately, but the later it is done the better for the atmosphere in the shops. The men get quickly accustomed to the saying : "Last week I earned 75 minutes per hour."

Moreover, this using of time shows, in many cases, that the workman has other work to do besides his work proper, e.g., moulding ; this other work has, strictly speaking, nothing, or not very much, in common with the work proper, but nevertheless it is absolutely necessary for production. These are the preparatory work, the auxiliary work, and some work losses, as will be explained more in detail later. This finding out of other work done by the men in doing their work proper is in itself a strong inducement to rationalising the work, as attention is drawn to details that may be unnecessary.

When speaking about analysis of time, only that part of the calendar time is referred to in this connection, which is available for the purpose of industrial production, i.e., the working periods or shift times. This analysis is shown in the accompanying chart, Fig. 1, which may be considered self-explanatory. This chart is given merely to show the existence of the several divisions of time ; they may vary in magnitude in relation to one another, and even may not be co-existent. Actually in use in practice are diagrams or charts of the kind shown in Fig. 2, illustrating the relation between conditions of men, equipment and material.

Considering now more in detail what has been called "working time" in Fig. 1, a scheme of further analysis is given in the next Fig. 3.

Most of the terms used in Fig. 3 do not need any explanation, but the following definitions may be of use : Piece-sequence time is the time between the beginning of a process on one piece and the beginning of the same process on the next piece, including an allowance for lost time in so far as this loss occurs during the piece-sequence time.

Falling off in the rate of working means the diminishing of the output resulting from the workmen's fatigue, due to continuous and trying work. This falling off in the rate of working does not always occur, but there are in foundries many cases where it can be observed, and if it is not taken into account trouble with the workmen is easily possible. The "special additions" refer to exceptional working conditions which may occur in consequence, to events not anticipated, such as rejects not due to incorrect workmanship, patching the moulds because of faulty patterns, etc.

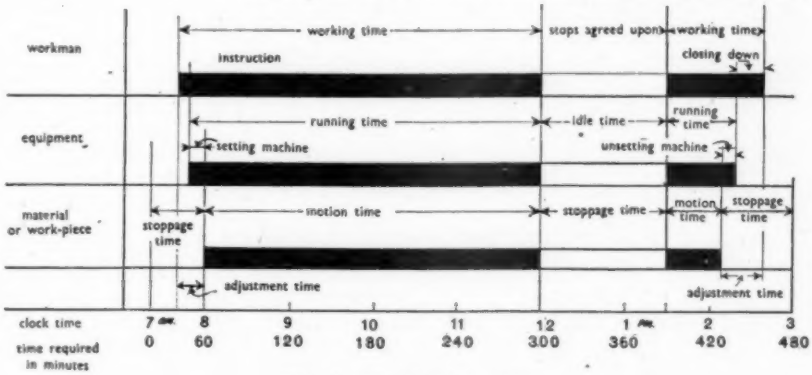


Fig. 2.—Production chart.

(To be continued.)

Institute of Metals.

Platinum Medal Award.

THE Council unanimously agreed to award the Institute of Metals Medal to Dr. Harold Moore, C.B.E., a Fellow of the Institute, of which he was President in 1934-36. Dr. Moore has had a long and distinguished metallurgical career, and will receive the medal as one who has rendered "outstanding services to non-ferrous metallurgy." He has been Director of the British Non-Ferrous Metals Research Association since 1932. Following his training under Dr. J. E. Stead, F.R.S., he held metallurgical posts with industrial firms before joining, as Chief Metallurgist, the Research Department, Woolwich, of which he was Director of Metallurgical Research from 1919-1932.

Dr. Moore is very well known and greatly respected throughout the non-ferrous metals industries, to which he has rendered invaluable services, as he has done also to the Institute of Metals ever since his election to membership twenty-three years ago.

The medal, which is offered to the Council of the Institute by the Mond Nickel Co., Ltd., for award annually, is of pure platinum, the metal of which it is composed being prepared at the company's refinery at Acton, London. This is the sixth occasion on which it has been presented, previous recipients having been Sir William Bragg (1938), Sir Harold Carpenter (1939), Dr. Paul Merica (1930), Dr. C. H. Desch (1941) and Sir W. Murray Morrison (1942).

The medal will be presented to Dr. H. Moore on the occasion of the annual general meeting to be held in London on March 3.

Conference on X-Ray Analysis

THE analysis of substances and the examination of their behaviour by X-ray diffraction methods has become of considerable importance in the war effort. The Institute of Physics is therefore arranging a second conference on the subject, to take place in Cambridge on April 9 and 10 next. The provisional programme includes a lecture on "Future Developments in X-ray Crystallography," by Prof. J. D. Bernal, and discussions on "Quantitative Treatment of Powder Photographs," "The Fine Structure of X-ray Diffraction," and "Fine Broadening." A report is to be presented to the conference on the progress made in the preparation of an index to X-ray Diffraction Photographs, for which the Institute has undertaken to be jointly responsible with the American Society for Testing Materials and the American Society for X-ray and Electron Diffraction.

Further particulars of the conference and of the Index can be obtained on request from the secretary of the Institute of Physics. (Temporary address: At the University, Reading.)

Ferranti - Wild-Barfield High-Frequency Industrial Heat Treatment

AN arrangement has been made between Messrs. Ferranti, Ltd., of Hollinwood, Lancashire, and Wild-Barfield Electric Furnaces, Ltd., Elecfurn Works, Watford, to collaborate in the development of high-frequency industrial heating equipment. This collaboration between the technical departments with the pooling of experience of both companies will enable more rapid advance to be made in the important fields of metallurgical heat-treatments and kindred processes.

The high-frequency generating equipment will be designed and manufactured by Ferranti, Ltd., whilst the heating, handling and quenching equipment will be manufactured by Wild-Barfield Electric Furnaces, Ltd. Sales and installation of the Ferranti-Wild-Barfield equipment will be handled by Wild-Barfield Electric Furnaces, Ltd., to whom all inquiries should be addressed.

Investigation of the Mechanical Properties of D.T.D. 304 and D.T.D. 298 Sand Castings

(*Continued from page* 146.)

view of the casting as a whole, any casting containing a region classed as "bad" would be rejected, while the fate of a casting with doubtful areas would be determined by the soundness of the rest of it, and the location of these areas.

The first point which stands out clearly from the results is that the properties of all the sections classed as "good" on radiography equal and usually exceed the specification values. It seems safe to conclude, therefore, that scatter of properties through a casting appearing entirely sound on radiography can be dismissed as negligible.

The next point to consider is to what extent the amount of scatter can be predicted in castings which show defects on radiography. This is a most important point because complicated castings on a large scale of production will never all be completely free from defects, and it is essential to have a reliable criterion of what can safely be passed. In the case of D.T.D. 304 the ultimate stress varies from 75·6% to 105·8%, and the elongation from 50% to 175% of the specification values. In the case of D.T.D. 298 these variations are from 78·6% to 120%, and 100% to 222% of the specification values. It is clear that whenever the radiography shows an indication of porosity the mechanical properties fall, and that in general the amount of this falling off agrees with the apparent severity of the defect shown by the radiograph. The lowest values were found in sections which would definitely have been scrapped on radiography. The results of B. 3 are somewhat anomalous, since the values are certainly lower than would have been expected from the amount of shrinkage shown by the radiograph. Even B. 3, however, which has the lowest values of any section which would have been passed on radiography, shows a tensile strength of 85·6% of the specification value, and it must be remembered that with such small tensometer pieces there is a considerable chance of a very small local defect causing an abnormally low result.

To sum up, it can be concluded as a result of this investigation that mechanical properties of actual castings in D.T.D. 304 and D.T.D. 298 can most safely be expected to exceed 80% of the specification values, and radiography can be relied on to reject castings whose properties would fall below this level. This conclusion carries with it a warning that the radiological technique must be critically selected, and that particularly in the case of castings of complicated sections it should be developed in conjunction with sectioning and metallographic examination.

It is realised that these results have their limitations. In the first place, the investigation has not covered the case of really large castings with sections up to several inches in thickness. It is held, however, that analogous conclusions would be reached. It is possible that radiography of thick sections would not be quite so sensitive in diagnosing scatter, but it is believed that a definite safety standard could be set at a level only slightly lower than 80%, and that even if foundry technique could not be made sufficiently good to produce castings regularly above this level, at least there would be no danger of allowing bad ones to go into service. The second main limitation which is realised is the comparatively small number of results. It is intended, however, to continue accumulating results on the above lines and also to check this method of investigation by having large numbers of radiographed castings tested as complete units. It is hoped to prepare another report in the near future when these further results are available.

The Minister of Supply has appointed Mr. R. D. Burn to be a Deputy-Controller in the Non-ferrous Metals Control.

A Note on the Damping Characteristics of Some Magnesium and Aluminium Alloys*

By L. R. Stanton, M.Sc., and Prof. F. C. Thompson, D.Met.

The damping capacities of some magnesium alloys have been measured at temperatures varying from about — 50° to 280° C., and for comparison the damping capacities of two typical aluminium alloys have also been determined. The authors conclude that, in general, the magnesium alloys have a distinctly higher value of P than have the aluminium base alloys, and for equal fibre stresses both materials have much greater damping capacities than has steel. In this abstract from the authors' paper attention is directed to the results obtained from the investigation and to the authors' conclusions.

DAMPING capacity, internal friction, or mechanical hysteresis, to give alternative designations to the same effect, is the property in virtue of which a substance can, of itself, dissipate internal vibrations, and hence prevent their attaining dangerous dimensions. Damping capacity, usually designated by P, represents the area of the mechanical hysteresis loop, which can be shown to be equal to twice the logarithetic decrement.

Reliable information is scanty regarding the damping properties of the alloys of magnesium, and their comparison with those of aluminium alloys. References to what work has been done are given in the English translation of Beck's comprehensive treatise: "The Technology of Magnesium and its Alloys."[1] Apart from these, the only values known to the authors are contained in a paper by Hatfield, Stanfield and Rotherham,[2] in which results are given of an investigation of two magnesium-base materials.

The present note leaves untouched a very big field of research in the damping characteristics of magnesium alloys, but in view of the impossibility of carrying on the work in present circumstances, it was considered advisable to publish those results which had been obtained.

The measurements made in the work described were obtained with the aid of the recording apparatus described by Contractor and Thompson,[3] modified in certain details in order to increase the accuracy of the results. With this apparatus the oscillations are recorded photographically, and the logarithmic decrement, δ, is calculated from the formula:—

$$\delta = \frac{\log_e A_1 - \log_e A_2}{20}$$

where A_1 is the amplitude corresponding to any desired fibre stress, and A_2 that of the twenty-first succeeding vibration. For ordinary values of damping capacity this leads to results practically identical with those obtained by other methods of calculation, but possesses the marked advantage that, for materials the damping capacity of which is very high, there is greatly increased sensitivity; this results in the various specimens being clearly differentiated, instead of being bunched together.

The specimens employed were 12 in. long, $\frac{5}{8}$ in. square at each end, turned down to 0·4 in. diameter over 2 in. in the middle. The use of this "short" specimen was determined by the need to obtain a uniform temperature distribution in the tests at temperatures above and below that of the room. The machining was done throughout with very great care, but even then duplicate test-pieces from adjacent portions of a single bar never gave identical results, though repeat tests on the same specimen showed good agreement.

Results

As the damping capacity of light alloys is appreciably higher than that of steel, the accuracy of measurement is correspondingly increased. The results given are the mean of two closely concordant tests, the first three runs being in each case disregarded, as experience has shown that these cannot be relied upon to give consistent results.

Magnesium Alloys.—Typical results for Elektron A8 D.T.D. 59A) in the cast condition are given in Fig. 1 (*a* and *b*) and Fig. 2. An initial maximum fibre stress of 1·56 tons/in.² was employed, a value which should be below the elastic limit in the case of all tests up to about 150° C., but which is somewhat above the limit at higher temperatures.† This is a matter of some importance in view of the fact that the same specimen was used for a whole series of tests, starting at room temperature and working upwards. This procedure has been adversely criticised,[3] but it is inevitable in view of the wide variations found in different test-pieces made from the "same" material. It may be pointed out that a similar procedure has been adopted by Hatfield and his co-workers.[2] The curious peak shown in Fig. 1*a* for the temperature of 135° C. was confirmed in repeat tests.

As, according to Vosskühler,[4] the elastic limit of Elektron A8 falls to 3,400 lb./in.² at 300° C., another set of tests was carried out with an initial maximum fibre stress of 1·05 tons/in.² In none of these, therefore, should the specimens have been over-stressed. The results are shown in Fig. 3. The main difference between these and the earlier results is the reduction in the values of P at the higher temperatures. A comparison of Fig. 3 with Fig. 1 is also of interest in giving an idea of the order of variation to be expected in duplicate test-pieces of the "same" material.

In all the runs on Elektron A8, both in the as-cast and in the heat-treated condition, the relatively low results obtained in the neighbourhood of 170° to 180° C. will be noted. The whole temperature range from 100° to 180° C., in fact, appears to be of some irregularity.

The results obtained for this alloy in the heat-treated state (D.T.D. 289) are shown in Fig. 4. The treatment consisted in heating at 385° C. for 8 hours, followed by 16 hours at 420° C. and air-cooling. An initial fibre stress of 1·05 tons/in.² was used, but although this value was low there was evidence of some slight permanent twist even at room temperatures. Above 200° C., the extent of this overstraining was very apparent, and the results, therefore, are given as approximate only. The heat-treated material has a damping capacity distinctly higher than that of the as-cast alloy, especially in the higher temperature range.

The results for Elektron AZM (D.T.D. 259) in the form of extruded bar at room temperatures and 50° C., using an initial stress of 1·1 tons/in.², are given in Table I; they lie between those for Elektron A8 in the cast and the heat-treated conditions.

As an example of forged material, Elektron AZ 855 (D.T.D. 322) was examined at room and sub-normal temperatures, and in view of its high elastic limit an

* *J. Inst. Metals*, Jan., 1943, pp. 29–42. This paper is among those to be presented for discussion at the Annual Meeting of the Institute of Metals, March 3, 1943.

† Where the initial stress has exceeded the elastic limit, there is a permanent twist on the test-piece and the curve does not return to the initial no-stress position.

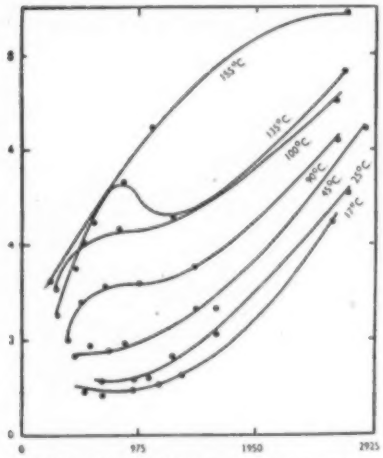


Fig. 1a.—Elektron A8 (as cast). Specimen No. 2. Maximum initial stress = 3,560 lb./in.²

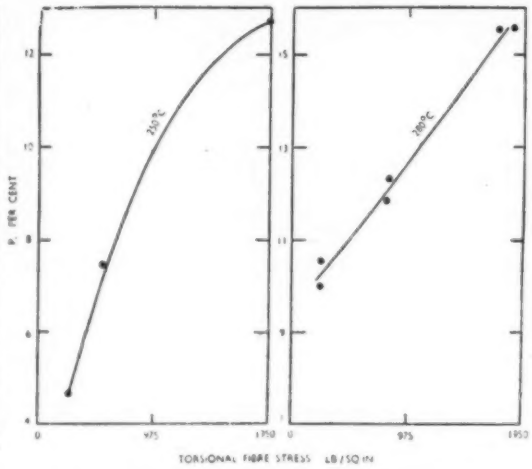


Fig. 1b.—Elektron A8 (as cast). Specimen No. 2. Maximum initial stress = 4,744 lb./in.²

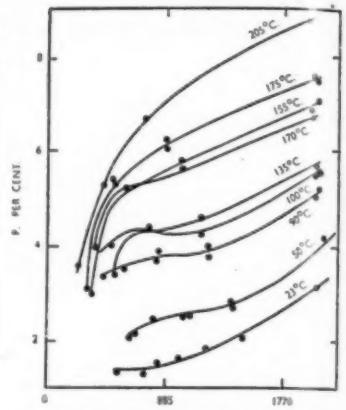


Fig. 2*.—Elektron A8 (as cast). Specimen No. 2. Maximum initial stress = 3,560 lb./in.²

* By reference to Fig. 1b, the widely different scales for the dotted curves for 250° and 280° C. in Fig. 2 will be noted.

initial stress of 2·68 tons/in.² was imposed. The results are shown in Fig. 5. It will be seen that the damping capacity increases appreciably as the temperature falls from 19° to — 40° C. So unexpected was this that repeat tests were made on another test-piece, with the same result; slight reduction of the damping value as a result of the low-temperature treatment. In order to obtain a final confirmation of this rise of P as the temperature falls below the normal, by excluding any possibility of the result being due to some defect in the machine, a series of tests was carried out at this stage on a steel specimen of known characteristics, with results strictly comparable with those previously obtained.

TABLE I.—AVERAGE VALUE OF DAMPING CAPACITY, %.

Material.	Initial Max. Fibre Stress, Tons/in.²	Torsional Fibre Stress, lb./in.²															
		375.				750.				1,500.				3,000.			
		Temperature, °C.															
		Low.	20°.	100°.	150°.	Low.	20°.	100°.	150°.	Low.	20°.	100°.	150°.	Low.	20°.	100°.	150°.
Elektron A8 (cast)	1·56	—	1·1	3·7	3·8	—	0·95	4·3	5·5	—	1·75	5·0	7·5	—	—	—	—
	1·05	—	1·4	3·9	4·2	—	1·4	4·25	5·3	—	2·25	4·6	6·3	—	—	—	—
Elektron A8 (heat-treated)	1·05	—	1·8	8·7	9·3	—	2·2	10·1	11·3	—	2·2	10·1	11·3	—	—	—	—
Elektron AZM	1·1	—	1·35	—	—	—	1·5	—	—	—	2·2	—	—	—	—	—	—
Elektron AZ 855	2·68	—	—	—	—	5·5	3·25	—	—	5·0	3·4	—	—	4·0	2·75	—	—
Duralumin B	1·83	—	—	—	—	*1·55	1·05	—	—	*1·6	1·2	—	—	*2·1	1·5	—	—
R.R. 56 (extruded)	1·83	—	—	—	—	*1·5	1·1	2·2	2·5	*1·8	1·4	2·7	3·4	*2·3	2·2	3·5	4·1
R.R. 56 (heat-treated)	1·83	—	—	—	—	*1·55	1·35	—	—	*1·65	1·95	—	—	*2·35	2·55	—	—

* Approximately 0° C.

Aluminium Alloys.—For comparison with the results obtained on the magnesium alloys, similar tests were carried out on extruded Duralumin B and on R.R. 56 in both the extruded and heat-treated conditions.

The results for the first of these alloys are shown in Fig. 6; the modulus of rigidity was taken as 4·0

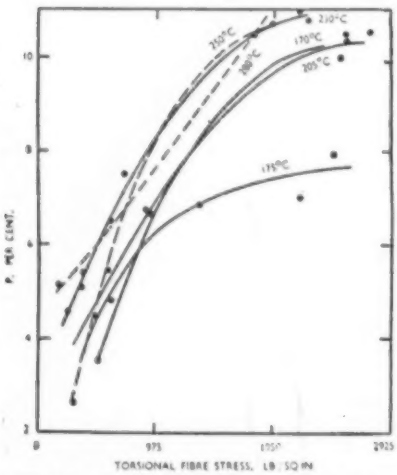


Fig. 3.—Elektron A8 (as cast). Specimen No. 3. Maximum initial stress = 2,345 lb./in.²

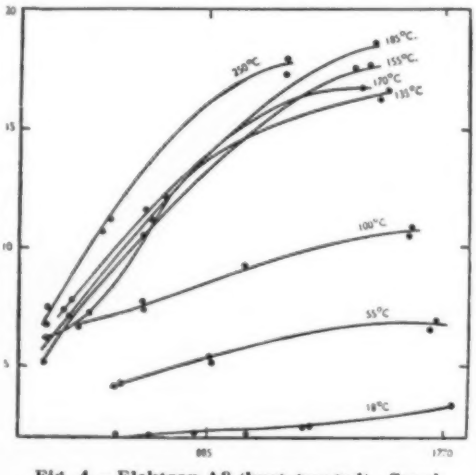


Fig. 4.—Elektron A8 (heat-treated). Specimen No. 1. Maximum initial stress = 2,345 lb./in.²

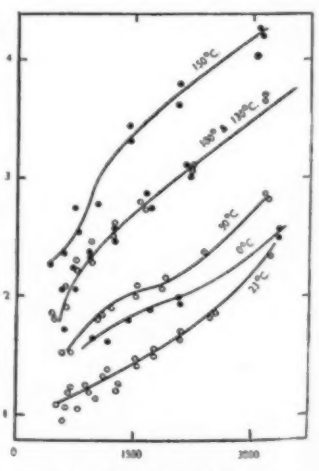


Fig. 7.—R.R. 56. Maximum initial stress = 4,000 lb./in.²

this was further confirmed by some figures which were obtained on Elektron AZM, though earlier in the research and before the conditions for low-temperature tests had been fully worked out. The curves for 24° C. were obtained after those at sub-normal temperatures, and indicate a × 10^6 lb./in.², and the initial stress was 1·83 tons/in.² The values for P at 50° C. were slightly lower than those for room temperatures, but at — 14° C. the damping had increased considerably. Results for — 30° C. fell roughly midway between the curves at 22° and at — 14°C.

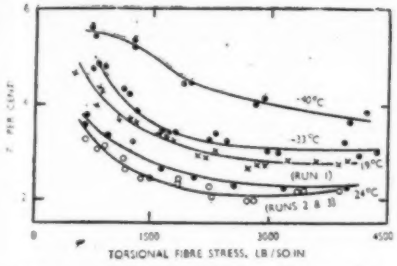


Fig. 5.—Elektron AZ855. Specimen No. 1. Maximum initial stress = 6,000 lb./in.²

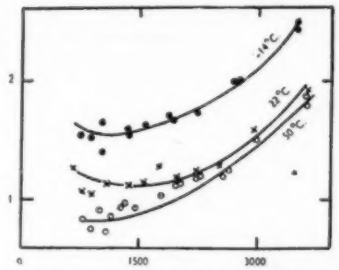


Fig. 6.—Duralumin B. Specimen No. 1. Maximum initial stress = 4,000 lb./in.²

In Fig. 7 are reproduced results for R.R. 56 in the extruded state. The initial stress was again 1·83 tons/in.², and even at 150° C. there was no sign of permanent deformation of the test-piece. In Table I are given some results of this material after heat-treatment. This Table gives typical results of all materials investigated.

Conclusions

At room and sub-normal temperatures Elektron AZ 855 has, in general, the highest damping capacity of the alloys tested. Whereas the values for Elektron AZ 855 tend to fall as the fibre stress is increased, those for both Elektron AZM and A8 (heat-treated) increase rapidly with the stress, with the result that at high fibre stresses the damping properties, especially of the former, will almost certainly exceed those of Elektron AZ 855 quite materially. At 100° C. Elektron A8 (heat-treated) has the highest value of P obtained in this work, that for aluminium alloys being far lower.

It appears that at all the stresses and temperatures investigated, the magnesium alloys examined have a higher damping capacity than have the aluminium alloys.

1 A Beck. "The Technology of Magnesium and Its Alloys." English Translation. London, 1940.
2 W. H. Hatfield, G. Stanfield and L. Rotherham, *Trans. North-East Coast Inst. Eng. Shipbuilders*, 1942, 58, 273.
3 G. P. Contractor and F. C. Thompson, *J. Iron Steel Inst.*, 1940, 141, 157.
4 H. Vosskühler, *Metallwirtschaft*, 1938, 17, 935.

Lord Hirst of Witton.

THE announcement of the death of Lord Hirst, chairman and managing director of the General Electric Co., Ltd., on January 22, 1943, would be received with deep regret by many readers. From a small beginning in 1886, when in association with Mr. Byng he opened what he called "a little electrical shop," sprang the great General Electric Co. undertaking, which was formed in 1889.

It was largely due to the inspiration, dynamic force and character of Lord Hirst that the company grew rapidly until it became a world-wide organisation with an issued capital of nearly £8,000,000 and employing over 50,000 people. He was 79 years of age and was still in control of the company up till the time of his death.

It has been said of Lord Hirst that by his own ability and gifts of character he made for himself an unchallenged position among the great employers of this country. He was among the first to realise the importance of research in industry and the G.E.C. Research Laboratories are among the finest industrial laboratories in the world. He had many interests, and his passing will leave many gaps not easily filled.

Nickel and the War.

IN a year-end statement, Mr. R. C. Stanley, chairman of the International Nickel Co. of Canada, Ltd., announces that the company's 35 million dollar expansion programme has reached a point where it now assures an increase in annual productive capacity of 50 million lb. of nickel over that of 1940. Even this spectacular increase, however, is not sufficient of itself to satisfy the ever-growing war needs of the United Nations, and must be supplemented by conservation, to ensure the most economical use of this vital war material.

In both these supplementary contributions to the war effort this company is taking an active share; its technical staffs on both sides of the Atlantic are aiding the nickel-consuming industries to reduce their requirements whenever practicable, advising on the most economical use of nickel, and offering technical assistance in connection with the utilisation of scrap. Such measures have already played an important part in lessening the demands on primary production and, in conjunction with the vastly increased output from the company's mines and refineries, should prove adequate for the essential needs of the Allies.

Tensile Properties of Aluminium Alloys

(*Continued from page* 136)

TABLE III.—BARS FOR MACHINING AND EXTRUDED SECTIONS.

Specification Number	Composition (%).*									Condition of Use.	Mechanical Properties.‡		
	Cu.	Mn.	Mg.	Si.	Fe.	Ti.	Ni.	Cr.	Others.		0·1% Proof Stress (Tons/sq. in.).	Ultimate Tensile Strength (Tons/sq. in.).	% Elongation on 2 in.
B.S.S. 6L1	3·5–4·5	0·4–0·7	0·4–0·8	0·7	0·7	0·3	—	—	—	Solution-treated and aged (3 in. dia. and under)	¾ in. & under: 14 Over ¾ in.: 15	24 25	15 15
B.S.S. 2L39	3·5–4·5	0·4–0·7	0·4–0·8	0·7	0·7	0·3	—	—	—	Solution-treated and aged (over 3 in. dia.)	Over 6–8 in.: 10·5 Over 3–6 in.: 12	20 22	8 12
B.S.S. 2L40	1·4–4·0	1·0	0·3–1·5	1·5	0·3–1·5	0·2	2·0	0·2	Ce 0·3 Cb 0·3	Solution-treated and artificially aged (up to 3 in. dia.)	Over ¾ in.: 21 ¾ in. & under: 20	27 26	10 10
B.S.S. 1A5	1·5–4·0	1·0	0·3–1·5	1·5	0·3–1·5	0·2	2·0	0·2	Ce 0·3 Cb 0·3	Solution-treated and artificially aged (over 3 in.)	Over 6–8 in.: 17 Over 3–6 in.: 19	23 25	6 8
D.T.D. 363	1·5–3·0	1·0†	0·2–4·0	0·6	0·6	0·3	1·0†	—	Zn 4·0–6·0	Solution-treated and artificially aged (up to 3 in. dia.)	27	33	8
D.T.D. 364A	3·0–4·5	1·2	1·0	1·0	1·0	—	—	—	—	Solution-treated and artificially aged	¾ in. & under 24 Over ¾ in.: 26	28 30	8 8
D.T.D. 423A	1·0	1·0	0·5–1·25	0·75–1·25	0·75	—	0·3	—	—	Fully heat-treated (up to 3 in. dia.)	17	22	8
D.T.D. 443	1·0	1·0	0·5–1·25	0·75–1·25	0·75	—	0·3	—	—	Solution-treated (up to 3 in. dia.)	10	17	15
D.T.D. 497	—	0·6	6·5–10·0	0·5	0·75	—	—	—	—	Soft	8	20	15
B.S.S. 1A4	—	1·5	1·0–3·0	0·7	0·7	0·2	0·35	0·5	—	Soft	—	11	1

* Single figures show maximum content: Remainder aluminium in each case.
† Only one of these elements shall be present.
‡ Single figures are minimum requirements of the Specification.

TABLE IV.—TUBES.

Specification Number.	Composition (%).*							Condition of Use.	Mechanical Properties.†			
	Cu.	Mn.	Mg.	Si.	Fe.	Ti.	Others.		Gauge.	§Proof Stress (Tons/sq. in.).	Ultimate Tensile Strength (Tons/sq. in.).	%Elongation on 2 in.	‡ Other Tests.
B.S.S. 5T4	3·5–4·5	0·4–0·7	0·4–0·7	0·7	0·7	0·3	—	Solution-treated and aged for 5 days	16G and under Over 16G–12G Over 12G	19 (2) 19 (2) 19 (2)	26 26 26	8 10 12·5	—
D.T.D. 190	—	0·6	6·5–10·0	—	0·75	—	—	Annealed	—	10 (1)	20–23	—	Flatten until distance between inner sides equals 5T or ¾ original bore
D.T.D. 186A	—	0·6	6·5–10·0	0·5	0·75	—	—	Hard	12G and under Over 12G	18 (1) 17 (1)	25 25	— —	Flatten until distance between inner sides equals 8T or ¾ original bore
D.T.D. 220A	1·5–2·5	—	0·4–1·0	1·0	0·8–1·5	0·12	0·5–1·5 Ni	Fully heat-treated and drawn to size	16G and under Over 16G–12G Over 12G	23 (2) 23 (2) 23 (3)	27 27 27	6 8 10	Proof bend test
D.T.I., 273	3·5–4·8	0·2–1·5	0·8–1·8	0·5	0·4	—	—	—	¼ in. and under Over ¼ in.	22 (1) 22 (1)	29 29	7 10	—
D.T.D. 310B	—	1·5	1·0–3·0	0·7	0·7	0·2	0·5 Ni 0·5 Cr	Soft	⅛ in.—½ in. ½ in.—¾ in. over ¾ in.	— — —	9 10 11	— — —	Drifting; flattening, bore and hydraulic tests
D.T.D. 460	1·0	1·0	0·5–1·25	0·75–1·25	0·75	—	0·3 Ni	Fully heat-treated and drawn to size	—	18 (1)	22	6	—
D.T.D. 464	3·0–4·5	1·2	1·0	1·0	1·0	—	—	Fully heat-treated	16G and under Over 16G–12G Over 12G	24 (2) 24 (2) 24 (2)	28 28 28	6 8 10	—
D.T.D. 520	3·5–4·5	0·4–0·7	0·4–0·8	0·7	0·7	0·3	—	Solution-treated, drawn, aged, and tempered	16G and under Over 16G–12G Over 12G	23 (2) 23 (2) 23 (2)	27 27 27	6 8 10	R = 5T
D.T.D. 140	—	1·5	1·0–3·0	0·7	0·7	0·2	0·5 Ni 0·5 Cr	As drawn	—	—	15	—	R = 3T
D.T.D. 150	1·0	1·0	0·5–1·25	0·75–1·25	0·75	—	0·3 Ni	Solution-treated and drawn to size	—	10 (1)	17	12	—

* Single figures show maximum content: Remainder aluminium in each case.
† Single figures are minimum requirements of the Specification.
§ (1) = 0·1% proof stress; (2) = 0·2 proof stress.
‡ Full details of tests must be obtained from specifications.
R = radius of bend. T = thickness of tube wall.

TABLE V.—FORGINGS AND BARS FOR FORGINGS.

Specification Number.	Composition (%).*									Conditions of Use.	Mechanical Properties†			
	Cu.	Mn.	Mg.	Si.	Fe.	Ti.	Ni.	Cr.	Others.		0·1% Proof Stress (Tons/sq. in.).	Ultimate Tensile Strength (Tons/sq. in.).	%Elongation on 2 in.	‡ Other Tests.
B.S.S. 6L1	3·5–4·5	0·4–0·7	0·4–0·8	0·7	0·7	0·3	—	—	—	Solution-treated and aged (3 in. dia. and under) —(¾ in. dia. and under)	15 14	25 24	15 15	—
B.S.S. 2L59	3·5–4·5	0·4–0·7	0·4–0·8	0·7	0·7	0·3	—	—	—	Solution-treated and aged (over 3 in. dia.)	15	25	15	—
B.S.S. 4L25	3·5–4·5	—	1·2–1·7	0·6	0·6 (1·0 total)	0·3	1·8–2·3	—	—	Solution-treated and aged Solution-treated	Forgings: 14 Pistons: — Cylinder heads: —	24 22 22	15 8 8	— — —
B.S.S. 2L40	1·5–4·0	1·0	0·3–1·5	1·5	0·3–1·5	0·2	2·0	0·2	Ce 0·3 Cb 0·3	Solution-treated and aged (3 in. dia. and under) —(¾ in. dia. and under)	21 20	27 26	10 10	—
B.S.S. L45	1·5–4·0	1·0	0·3–1·5	1·5	0·3–1·5	0·2	2·0	0·2	Ce 0·3 Cb 0·3	Solution-treated and aged (over 3 in. dia.)	21	27	10	—
B.S.S. 2L42	1·5–3·0	—	1·2–1·8	1·3	1·0–1·5	0·2	0·5–1·5	—	—	Solution-treated and aged	—	25	6	—
D.T.D. 130A	1·8–2·5	—	0·65–1·2	0·55–1·25	0·6–1·2	0·05–0·15	0·6–1·4	—	—	Solution-treated and artificially aged (up to 3 in. dia.)	21	27	10	—
D.T.D. 147	3·5–4·5	0·4–0·7	0·4–0·7	—	0·75	—	—	—	—	Solution-treated and aged	13·5	22·5	15	Bend and fracture tests
D.T.D. 130A	3·5–4·5	0·4–0·7	0·4–0·8	0·7	0·7	0·3	—	—	—	Solution-treated and aged	13·5	22·5	15	Fracture test
D.T.D. 364A	3·0–4·5	1·2	1·0	1·0	1·0	—	—	—	—	Solution-treated and aged	26	30	8	—
D.T.D. 297	—	0·6	6·5–10·0	0·5	—	—	—	—	—	Soft	8	20	15	—
D.T.D. 324	0·7–1·3	—	0·8–1·5	11·5–13·0	—	—	0·7–1·3	—	0·6	Solution-treated and aged	—	20	3	—
D.T.D. 410	1·8–2·5	—	0·65–1·2	0·55–1·25	0·6–1·2	0·05–0·15	0·6–1·4	—	—	Solution-treated and artificially aged (over 3 in. dia.)	21	27	10	—
D.T.D. 423A	1·0	1·0	0·5–1·25	0·75–1·25	0·75	—	·03	—	—	Solution-treated and aged (up to 3 in. dia.)	17	22	8	—
D.T.D. 443	1·0	1·0	0·5–1·25	0·75–1·25	0·75	—	0·3	—	—	Solution-treated (up to 3 in. dia.)	10	17	15	—

* Single figures show maximum content: Remainder aluminium in each case.
† Single figures are minimum requirements of the Specification.
‡ Full details of tests must be obtained from Specifications.

A Critical Consideration of Some Applications of the Spectograph to Steelworks Analysis

By H. T. Shirley, B.Sc., A.R.C.S., and A. Elliott, A.Met.

Developments in the technique and application of spectrographic methods to quantitative analysis have been rapid inrecent years. In regard to steel, F. G. Barker[2] discussed and laid down a detailed procedure for the application of the spectrograph to low-alloy materials. The present authors have studied in considerable detail the application of such a method to routine steelworks analysis, and this report of their investigations, presented at a joint meeting in Sheffield on February 13, 1943, of members of the Iron and Steel Institute, the Sheffield Metallurgical Association, the Sheffield Society of Engineers and Metallurgists, and the South Yorkshire Section of the Institute of Chemistry, discusses the possibilities of the whole technique and various precautions and modifications introduced to minimise maximum errors. Here are given abstracts from the report.*

CHEMICAL analysis has in many directions reached such a high standard of speed and accuracy that the merits of any alternative procedure must receive the most careful scrutiny if disappointment is to be avoided. This is certainly true in the case of much steel analysis.

In recent years the application of the spectrograph to quantitative analysis, as an alternative to the more normal chemical methods, has been developed and explored with increasing intensity, and many papers and articles have appeared dealing with its use in the most diverse fields. Under such conditions of rapid development some suggested applications of the method to fields where, in its present stage, it must prove inferior to existing chemical procedure are to be expected. Nevertheless, there are directions in which the spectrographic methods has proved of very material value in steel analysis, and it is hoped that the present critical consideration of the application of the process to the analysis of a variety of alloy steels will help in defining the present limits of usefulness, besides suggesting lines of further development.

A good deal of the spectrographic work on steel carried out in America has centred round the development of methods for the rapid production of pass-test analyses, as, for example, in the work of Vincent and Sawyer at Michigan University, and its commercial application by the Ford Motor Co.[1] Success in this sphere demands careful preliminary study with subsequent intensive organisation and team work. It is also necessary that conditions should be suitable in regard to the variety of steels, the number and rate of delivery of samples, and the required limits of accuracy. Given these, improvement is claimed over normal chemical procedure.

In Great Britain, Barker[2] has dealt with the subject from the alternative angle of the general routine analysis of miscellaneous samples of low-alloy and carbon steels, of composition ranging up to 4½% of nickel, 1·6% of chromium, 2% of manganese, 0·7% of molybdenum, and 0·3% of silicon and vanadium. It was on the basis of the detailed discussion of the method and procedure given in Barker's paper that the authors commenced their study of the application of the spectrographic method to steelworks analysis. In the initial stages the work was therefore mainly concerned with carbon and low-alloy steels, but practical development was eventually largely concentrated on certain higher-alloy steels.

* Paper No. 18/1943 of the Committee on the Heterogeneity of Steel Ingots (submitted by Dr. W. H. Hatfield, F.R.S.). Advance Copy.

1 H. B. Vincent and R. A. Sawyer. "Routine Spectroscopic Analysis in Ford Motor Co. Foundry." *Metal Progress*, 1939, vol. 36, July, pp. 35–39; also *Proceedings of the Seventh Summer Conference on Spectroscopy and Its Applications* (Massachusetts Institute of Technology), 1939, pp. 16–18.

2 F. G. Barker. "Some Applications of the Spectrograph to the Quantitative Analysis of Ferrous and Non-Ferrous Metals." *Journal of the Iron and Steel Institute*, 1939, No. I, pp. 211 P–245 P.

Apparatus Used and General Principles of the Method

There are now various types of spectrographic apparatus on the market, including prism and grating spectrographs and recording and non-recording photometers. For the work here described the authors have used essentially the same apparatus as that very fully described in Barker's paper (*loc. cit.*), consisting of Hilger large quartz spectrographs Hilger non-recording photo-electric microphotometers and the Judd Lewis comparator for the general qualitative comparison and examination of plates and preliminary work on line selection.

The general principles of spectrographic technique are now widely understood. Briefly, in the work here described, the specimen to be analysed is used as one electrode, and a pointed carbon rod as the other. Passage of current from a 15,000-V. transformer across the gap between the electrodes vapourises some of the steel and causes it to emit light of wave-lengths which are characteristic of the particular elements present. The spectrograph splits up the composite light so emitted, giving a series of lines on a photographic plate, each line corresponding in position to light of a given wave-length and in blackness to the intensity of the light of that particular wave-length. The intensity of light of any selected wave-lengths can then be determined from the density of the corresponding line on the photographic plate, this density being measured by the photo-electric photometer. The results of such determinations are then related to the composition of the sample by means of curves based on the response of "standard" samples of known chemical analysis under similar conditions.

In practice various corrections are required, and a first correction for fluctuation in the general density of the spectra is made by plotting, not the simple intensity or log. intensity against composition, but the log. ratio of the photometer readings for the selected line of the element in question and a suitable comparison iron line,† the iron line being used as a measure of the general relative density of the spectrum under consideration.

With careful work, and without further correction, it will usually be found that most of the errors are within ± 5% of the amount of the element present, but occasional errors up to as much as ± 10% will occur. This is well brought out by Table XIII of Barker's paper, in which the errors on fifty casts of nickel-chromium-molybdenum steel are summarised, using three spectra for each determination. Thus, for example, occasional errors of as much as ± 0·25% on 2·5–3·5% nickel are found. Errors of this magnitude

† Some workers plot log. ratios against log. composition for further simplification of line form, but the authors have not found any practical advantage from this in their work.

are, of course, too high for analytical work with steel melted to narrow specification limits if the melting tolerance is not to be entirely absorbed by the spectrographic error.

Detailed Consideration of Technique in Relation to Sources of Error

Before describing the technique employed and the results obtained with different types of steel, the authors consider in some detail a number of sources of error and means adopted for reducing their effects. They point out that, at the present stage of development, errors in spectrographic analysis are often considerably greater than those of alternative chemical procedure and possible advantages in speed or economy can only be exploited where the magnitude of the errors, coupled with the wideness of the melting specifications, makes their toleration possible.

Variations introduced during the taking of spectra can easily arise from differences in the brightness and stability of the spark, with subsequent alteration of the effective exposure of the photographic plate, as well as the possible introduction of variations in the relative intensities of the light, giving rise to the various lines. Stabilisation of the primary voltage applied to the transformer is an obvious precaution to minimise such changes, but in the authors' experience reasonable fluctuations here are not of great importance. The chief causes of variation are defects in the surface of the steel or carbon-electrode points, causing unsteady sparking and inaccuracy in setting the gap between the two electrodes, variations in the width of which seriously modify the spark intensity. This question of the size of gap is of very considerable importance, and it should always be set with the greatest possible accuracy consistent with the required speed of working.

The influence of variation in the gap width has been studied in detail for a number of steels, and the type of results obtained is tabulated from experiments with a high manganese-nickel-chromium-vanadium steel in which the gaps used were $\frac{1}{8}$ in., $\frac{1}{4}$ in., and $\frac{3}{4}$ in. wide.

Alteration in the gap width can have two effects. In the first place, it modifies the intensity of the spark, and therefore the overall intensity of the light emitted. This change can be allowed for by using the characteristic response curve of the photographic plate to convert the photometer readings into terms directly related to the actual light intensity. The log. ratio for the element line and the iron comparison line should then remain unaltered by the change in overall brightness. The successful application of such "photo-correction" is shown by the results of the disc experiments. In addition to the overall intensity change, however, there may be appreciable changes in the relative intensities of the lines for the various elements induced by modification of the gap width. This is shown in results from tests in which the gap width was modified and the time of exposure kept constant.

The results of experiments indicated that the most stable region for the gap width for steel A is between 2 mm. and 3 mm., and, similar results having been obtained for the other steels tested, the authors have standardised on a $2\frac{1}{2}$ mm. gap as being the width least likely to introduce variations from slight divergencies of gap adjustment.

Duplicate Spectra.—The authors' normal procedure is to use the average values from two spectra for the analysis of each sample. In most cases it is not practicable to consider the use of more than two for each sample, but this duplication is definitely worth while, permitting immediate checking of doubtful results and giving some general increase in accuracy. To obtain the fullest benefit from this checking, the authors arrange the duplicate spectra adjacent to one another. Although only two spectra are used for each sample, each spectrum is in fact a composite of two or three superimposed exposures taken at different points on the surface of the specimen. As pointed out by Barker,* this procedure tends to minimise segregation effects; it also reduces errors resulting from inaccuracy in setting up specimens and electrodes and any other errors arising from variations introduced during the taking of the spectra.

The Selection of Line Pairs.—The ideal is to use only pairs of lines which are truly homologous, occur close together, and are of similar density. Unfortunately, search through the complex spectra of the higher alloy steels often fails to discover such perfectly adjusted line pairs, and resource must be had to those giving greatest accuracy under practical working conditions. The authors' work on plate calibration and line selection has been constantly referenced to the iron arc spectrum, using the Hilger map for identification of the lines, while extensive use has been made of Harrison's Wave-Length Tables[3] to confirm and identify lines of the other elements. In this way, and by the comparison of spectra prepared from samples approximating to the types of steel under consideration, but showing fairly wide differences in the content of individual elements, it has been possible to select visually in the Judd Lewis comparator the most hopeful lines for final study in the photometer.

The ultimate choice of lines has been based on the degree to which they fulfil the following criteria: Satisfactory density, sensitivity, availability of suitable iron line, and freedom from interference by other lines.

The Method of Processing the Plates.—After many variations in procedure, and bearing in mind that the method adopted should be simple and easily reproducible by different workers, the authors eventually standardised a method in which the plate is lowered horizontally into the solution and squeegeed lightly with a flat rubber squeegee for a few seconds, agitated in a random manner for a few more seconds, and then left without further agitation until development is completed.

In deciding on the type of developing solution to be used and the time and temperature, it must be borne in mind that all these, together with the type of plate, influence the density and contrast of the image obtained, and a suitable combination must be found by experience which will give the maximum contrast consistent with satisfactory reading of the required lines. Standardisation should be assisted by the adoption of some simple precaution to keep the temperature of the developer constant.

Adjustment for Varying Speed of Plates.—A decrease in the speed of plates is to be expected with age, and variation has been found in practice between boxes from a single delivery under the present war-time conditions. In cases where the lines to be measured are of widely differing densities, covering most of the available range of the plate, some modification in procedure must be introduced to correct for such variations in speed.

Modification of exposure is the most obvious method for modifying density, but unfortunately this is liable to introduce an appreciable modification in the log.-ratio/concentration relationships for the various elements, and while the use of standard samples permits a correction to be applied for this, it is considered better to avoid any considerable modification of the exposure as far as possible. Alternatively, adjustment may be effected by variation of the time of development. Under the authors' conditions they have found so close a correspondence in the shape of the characteristic curves for development times between 2 and 4 mins. that there is no need for modification over this range.

The Use of "Standard" Samples.—Some variation occurs in the composition curves from plate to plate, and a further increase in accuracy is possible by the use of "standard" samples. The authors use from two to four such samples

* *loc. cit.*, p. 242 F.

3 By far the best available collection of data on this important subject and containing particulars of more than 100,000 lines. (Published by John Wiley, Inc., and Chapman and Hall, Ltd., 1939.)

on each plate, and these usually include one or two samples from recent casts to cover any day-to-day variation in the response of the material.[4] On the basis of the average behaviour of these standards small corrections are applied to the results read from the composition curves, or the curves themselves are moved relative to the axes.

Chemical Checks.—The standards referred to in the preceding paragraph are usually taken from the previous day's chemical checks. The number of such chemical analyses required to keep an effective check on general accuracy is a matter which must be decided by experience. Analysis of one sample in twenty should be sufficient when thorough experience has been gained, provided that this is not less than one analysis per day. For certain elements, when the amount present is considerable and the line used is not very sensitive, provided that the chemical analysis does not involve any great trouble or loss of time, it may be found worth while to increase the number of chemical checks to, say, one in ten. This applies to nickel in the authors' work with steels A and B, for which a one-in-ten check permits rather closer correspondence to the chemical figures than would otherwise be the case.

The Influence of the Range of Composition.—The most satisfactory routine results from spectrographic analyses are to be expected where production arrangements make it possible to deal with a continuous flow of samples to one specification. Individual plates can then be arranged to contain only a single type of steel, and the limited portion of the composition/log.-ratio required can generally be represented as straight lines. The small number of standards required then have their maximum correcting efficiency, correction being satisfactorily applied by the simple addition of a constant difference to results read from fixed composition curves. This represents the condition under which the authors have worked for many thousands of casts of the high-alloy steels A and B, detailed procedure for which is given.

On the other hand, satisfactory application of the method to the routine analysis of low-alloy materials would, in the authors' case, demand the inclusion on individual plates of a wide variety of steels, with the result that four or five standards, at most, would have simultaneously to characterise the curves for five elements fluctuating independently over ranges, which for nickel could be as great as from 0·1% to 5·5% and for chromium from 0·05% to 3·5%. Moreover, the densities of the lines used will vary over very much wider limits than when dealing with a single type of steel. The highest possible accuracy is not to be expected under such conditions.

Working Procedure and Results For High-Alloy Steels A and B

The greater part of the authors' routine work has been concerned with two high-alloy materials, typical analyses of which are :—

	Steel A. %		Steel B. %
Silicon	0·9	..	1·2
Manganese	5·5	..	0·5
Chromium	5·0	..	14·5
Nickel	12·5	..	12·5
Vanadium	0·3	..	—
Tungsten	—	..	3·0

The actual procedure followed by the authors is given in detail. From a study of the spectra of these materials line pairs were selected as indicated in the following table :—

LINE PAIRS SELECTED FOR ANALYSIS OF STEELS A AND B.

Steel.	Silicon.	Manganese.	Chromium.	Nickel.	Vanadium.	Tungsten.
A	Si 2881·58	Mn3488·68	Cr 3408·76	Ni 3510·34	V 3102·30	—
	Fe 2875·34	Fe 3490·57	Fe 3407·46	Fe 3497·84	Fe 3100·67	—
B	Si 2881·58	Mn2933·06	Cr 3391·43	Ni 3510·34	—	W 4008·75
	Fe 2885·93	Fe 2936·90	Fe 3407·46	Fe 3497·84	—	Fe 4009·72

4 J. R. Handforth, H. W. Whymper, and W. M. Boulton. "Spectrographic Analysis and its Application to Aluminium Alloys." *Metal Treatment*, 1939, vol. 5, Spring Issue, pp. 3–12.

The amount of deviation from the correct figures varies in spectrographic work with the amounts of the particular elements present and the sensitivity of the lines used. This latter is a very variable quantity, as shown by the figure given in the following table :—

TYPICAL EQUIVALENT PERCENTAGE CHANGE IN COMPOSITION FOR A LOG.-RATIO CHANGE OF 0·1.

Element.	Steel A.		Steel B.
Silicon	0·4	..	0·5
Manganese	1·1	..	0·2
Chromium	1·3	..	2·0
Nickel	2·2	..	2·4
Vanadium	0·1	..	—
Tungsten	—	..	0·75

From these figures it is clear that, while errors in the estimation of vanadium are likely to be very small, the determination of nickel, for example, must be very carefully carried out if errors are to be kept with $\frac{1}{4}$% of this element. The maximum routine spectrographic errors normally experienced in the case of the other elements are :—

Silicon	± 0·1%.
Manganese	± 0·2% in steel A and ± 0·03% in steel B.
Chromium	± 0·2% in steel A and ± 0·3% in steel B.
Tungsten	± 0·15%.

RESULTS OF TWENTY-FIVE CHEMICAL CHECKS WITH CORRESPONDING SPECTROGRAPH FIGURES COVERING 400 ROUTINE SAMPLES OF STEEL A.

Cast No.	Silicon.		Manganese.		Chromium.		Nickel.		Vanadium.	
	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.
1753	0·91	0·91	5·66	5·6	4·96	5·05	12·57	12·75	0·35	0·34
1770	0·85	0·89	5·69	5·8	4·98	4·85	12·45	12·65	0·35	0·36
1788	0·90	0·85	5·65	5·70	4·91	4·95	12·47	12·3	0·34	0·34
1802	0·92	0·87	5·76	5·6	4·95	4·85	12·59	12·7	0·34	0·33
1819	0·93	0·94	5·75	5·7	4·91	4·95	12·49	12·35	0·34	0·34
1835	0·87	0·97	5·66	5·75	4·93	5·05	12·46	12·7	0·33	0·34
1849	0·91	0·93	5·67	5·7	4·89	4·85	12·49	12·45	0·32	0·35
1867	0·90	0·94	5·67	5·7	4·94	5·1	12·56	12·3	0·32	0·33
1885	0·93	0·96	5·67	5·8	4·96	5·0	12·68	12·5	0·32	0·34
1903	0·91	0·91	5·72	5·75	4·92	5·0	12·57	12·5	0·33	0·33
1917	0·94	0·90	5·70	5·6	4·88	4·85	12·59	12·5	0·33	0·32
1933	1·06	1·08	5·82	5·85	4·91	5·0	12·55	12·4	0·32	0·35
1954	0·98	0·95	5·78	5·6	4·78	4·85	12·60	12·7	0·34	0·32
1971	1·03	1·01	6·12	5·85	4·59	4·8	12·67	12·6	0·34	0·33
1987	1·00	0·99	5·70	5·7	4·89	4·8	12·67	12·7	0·33	0·34
2007	0·90	0·89	5·65	5·55	4·91	4·8	12·62	12·5	0·33	0·33
2025	0·93	0·93	5·68	5·65	4·78	4·7	12·80	12·8	0·34	0·34
2047	0·93	0·91	5·65	5·65	4·88	4·85	12·71	12·75	0·34	0·33
2065	0·92	0·91	5·72	5·7	4·92	4·95	12·77	12·7	0·35	0·34
2081	0·95	0·94	5·40	5·55	4·90	4·90	12·40	12·25	0·34	0·33
2099	0·87	0·88	5·32	5·4	5·06	4·9	12·42	12·4	0·33	0·33
2119	0·90	0·85	5·39	5·35	4·81	4·6	12·49	12·45	0·33	0·32
2139	0·95	0·95	5·36	5·45	5·02	4·9	12·37	12·5	0·34	0·34
2157	0·88	0·90	5·32	5·5	5·16	4·95	12·34	12·3	0·35	0·34
2176	0·89	0·88	5·37	5·45	5·05	4·95	12·42	12·45	0·35	0·33

RESULTS OF TWENTY-FIVE CHECKS WITH CORRESPONDING SPECTROGRAPHIC FIGURES COVERING 400 ROUTINE SAMPLES OF STEEL B.

Cast No.	Silicon.		Manganese.		Chromium.		Nickel.		Tungsten.	
	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.	Chemical.	Spectrographic.
7101	1·36	1·33	0·57	0·55	14·65	14·55	12·28	12·3	2·72	2·92
7116	1·52	1·47	0·59	0·59	14·53	14·65	12·47	12·35	2·63	2·79
7131	1·47	1·36	0·57	0·55	14·67	14·65	12·55	12·5	2·70	2·75
7147	1·44	1·40	0·55	0·51	14·63	14·45	12·44	12·55	2·69	2·75
7163	1·48	1·38	0·58	0·57	14·45	14·55	12·51	12·25	2·59	2·67
7178	1·55	1·40	0·56	0·53	14·56	14·65	12·50	12·35	2·80	2·68
7194	1·40	1·42	0·61	0·64	14·68	14·5	12·62	12·65	2·65	2·76
7209	1·44	1·42	0·58	0·58	14·63	14·6	12·63	12·55	2·73	2·64
7225	1·54	1·48	0·58	0·54	14·53	14·55	12·65	12·75	2·65	2·68
7237	1·53	1·44	0·54	0·49	14·67	14·6	12·61	12·55	2·69	2·67
7252	1·59	1·56	0·54	0·52	14·62	14·8	12·48	12·55	2·69	2·70
7268	1·26	1·31	0·57	0·56	14·86	14·6	12·54	12·75	3·01	2·97
7282	1·19	1·18	0·54	0·51	14·84	14·7	12·49	12·55	2·81	2·94
7297	1·48	1·41	0·57	0·53	14·56	14·65	12·61	12·7	2·89	2·85
7312	1·29	1·37	0·62	0·60	14·44	14·75	12·71	12·6	2·69	2·85
7326	1·40	1·43	0·56	0·49	14·63	14·6	12·60	12·55	2·73	2·89
7341	1·48	1·50	0·57	0·58	14·52	14·55	12·35	12·75	2·67	2·76
7357	1·55	1·43	0·60	0·57	14·56	14·7	12·60	12·4	2·65	2·80
7373	1·46	1·50	0·54	0·52	14·52	14·75	12·62	12·45	3·63	2·75
7386	1·51	1·49	0·59	0·55	14·57	14·5	12·58	12·6	2·67	2·72
7402	1·34	1·50	0·60	0·59	14·70	14·65	12·56	12·5	2·63	2·87
7417	1·48	1·47	0·62	0·63	14·69	14·8	12·72	12·6	2·66	2·76
7434	1·40	1·43	0·56	0·55	14·81	14·7	12·75	12·6	2·69	2·77
7449	1·50	1·43	0·57	0·51	14·66	14·6	12·67	12·75	2·65	2·63
7466	1·46	1·46	0·56	0·54	14·62	14·7	12·68	12·7	2·66	2·75

SPECTROGRAPHIC ANALYSIS OF LOW-ALLOY STEELS USING PHOTO-CORRECTION FROM CHARACTERISTIC PLATE RESPONSE CURVE.

Silicon.			Manganese.			Chromium.			Nickel.			Molybdenum.			Vanadium.		
Chemical Figure.	Spectrographic Difference.		Chemical Figure.	Spectrographic Difference.		Chemical Figure.	Spectrographic Difference.		Chemical Figure.	Spectrographic Difference.		Chemical Figure.	Spectrographic Difference.		Chemical Figure.	Spectrographic Difference.	
	B.	C.		B.	C.		B.	C.		B.	C.		B.	C.		B.	C.
0·28	−0·02	−0·02	0·64	+0·03	+0·03	0·12	0·00	0·00	3·48	−0·13	+0·04	—	—	—	—	—	—
0·29	+0·02	+0·02	0·58	−0·01	−0·00	1·66	+0·01	+0·02	0·07	+0·04	0·00	0·32	0·00	−0·01	—	—	—
0·26	+0·01	+0·01	0·55	0·00	−0·01	1·64	+0·03	−0·01	0·09	+0·04	−0·01	0·23	0·00	−0·01	—	—	—
0·20	+0·01	+0·01	0·36	−0·01	−0·02	0·08	−0·01	+0·01	2·96	−0·11	+0·06	—	—	—	—	—	—
0·18	+0·03	+0·04	0·29	−0·02	−0·01	0·08	+0·04	+0·02	4·92	−0·17	+0·10	—	—	—	—	—	—
0·22	+0·03	+0·03	0·43	−0·01	+0·02	0·46	+0·04	+0·01	2·74	−0·02	−0·01	—	—	—	—	—	—
0·27	−0·02	+0·01	0·35	−0·03	−0·03	1·39	−0·06	−0·01	0·10	−0·01	−0·03	0·72	+0·04	−0·01	—	—	—
0·28	−0·02	0·00	0·59	−0·03	0·00	0·83	0·00	+0·04	3·64	−0·13	+0·01	—	—	—	—	—	—
0·21	+0·01	+0·01	0·24	−0·01	0·00	0·08	−0·02	+0·01	4·93	−0·02	+0·08	—	—	—	—	—	—
0·23	0·00	+0·02	0·69	−0·02	−0·02	0·17	+0·01	−0·02	3·59	−0·03	+0·06	—	—	—	—	—	—
0·34	−0·02	0·00	0·41	0·00	+0·03	3·15	−0·17	−0·04	0·25	+0·02	−0·01	0·49	−0·02	+0·01	—	—	—
0·30	−0·01	+0·01	0·37	−0·02	−0·02	1·53	−0·01	+0·01	0·13	+0·05	0·00	—	—	—	—	—	—
0·31	−0·01	−0·01	0·53	−0·04	+0·01	1·70	−0·03	−0·02	0·15	+0·03	0·00	0·22	+0·01	+0·01	—	—	—
0·23	+0·03	+0·03	0·57	−0·02	+0·01	0·10	+0·02	−0·03	3·62	+0·03	+0·01	—	—	—	—	—	—
0·27	0·00	+0·02	0·30	−0·02	−0·01	1·50	+0·03	+0·05	0·13	+0·04	+0·01	—	—	—	—	—	—
0·22	+0·03	+0·03	0·26	+0·02	+0·02	0·07	−0·03	+0·03	4·87	−0·12	−0·09	—	—	—	—	—	—
0·21	0·00	+0·01	0·28	−0·01	0·00	0·05	+0·03	−0·01	4·88	−0·03	0·00	—	—	—	—	—	—
0·22	+0·03	+0·03	0·45	−0·03	−0·01	0·12	+0·02	+0·05	2·72	+0·04	−0·05	—	—	—	—	—	—
0·24	0·00	+0·01	0·19	0·00	−0·02	0·06	−0·01	+0·01	0·07	+0·08	+0·08	—	—	—	—	—	—
0·70	−0·01	+0·01	0·53	−0·01	0·00	1·62	+0·09	+0·08	0·16	+0·02	0·00	0·21	0·00	0·00	—	—	—
0·26	−0·01	−0·03	0·64	−0·01	−0·02	0·88	0·00	+0·01	0·13	+0·02	−0·03	—	—	—	—	—	—
0·20	−0·01	0·00	0·26	−0·01	−0·02	0·08	0·00	+0·02	4·96	−0·16	−0·03	—	—	—	—	—	—
0·14	+0·01	0·00	0·28	+0·01	0·00	0·09	+0·01	0·00	0·28	0·00	−0·02	—	—	—	—	—	—
0·19	−0·02	−0·01	0·31	0·02	0·02	Trace	—	—	4·92	−0·12	+0·10	—	—	—	—	—	—
0·22	0·00	0·00	0·39	+0·02	+0·01	0·06	+0·02	+0·02	5·35	−0·08	+0·06	0·24	−0·02	−0·02	—	—	—
0·20	0·00	−0·02	0·29	+0·01	+0·02	0·09	0·00	+0·02	5·37	−0·01	−0·05	0·25	0·00	−0·01	—	—	—
0·18	+0·02	+0·02	0·37	0·00	+0·01	0·80	0·00	+0·07	3·34	−0·04	+0·09	—	—	—	—	—	—
0·25	−0·03	−0·02	0·74	0·00	−0·01	0·06	+0·01	+0·01	0·56	−0·09	−0·01	—	—	—	—	—	—
0·75	0·00	+0·01	0·55	−0·02	+0·02	1·75	+0·04	+0·10	0·25	+0·03	+0·01	0·21	−0·01	+0·01	—	—	—
0·24	−0·02	−0·01	1·23	+0·02	+0·06	Trace	—	—	0·14	+0·02	−0·01	—	—	—	—	—	—
0·22	0·00	0·00	0·45	−0·03	−0·02	3·08	0·00	−0·11	0·21	−0·02	0·00	0·42	−0·03	0·00	—	—	—
0·25	+0·01	0·00	0·13	+0·01	0·00	2·01	−0·03	+0·04	1·94	−0·05	0·00	—	—	—	—	—	—
0·27	−0·01	+0·01	0·47	+0·01	−0·03	0·11	+0·02	0·00	0·15	−0·01	−0·01	—	—	—	—	—	—
0·31	−0·02	+0·03	0·55	+0·02	+0·01	1·67	+0·01	−0·04	0·09	+0·02	−0·01	0·21	0·00	−0·01	—	—	—
0·22	−0·01	−0·01	0·68	+0·02	+0·02	0·09	−0·02	−0·02	2·55	+0·10	+0·05	—	—	—	0·17	−0·02	−0·02
0·21	+0·01	+0·02	0·64	+0·02	+0·03	0·10	+0·01	−0·02	3·28	+0·09	+0·06	—	—	—	—	—	—
0·25	+0·05	+0·03	0·14	+0·03	+0·01	2·23	−0·03	−0·04	2·18	+0·07	+0·03	—	—	—	—	—	—
0·28	−0·03	0·00	0·50	−0·01	+0·02	1·39	+0·01	−0·01	0·13	+0·03	+0·03	—	—	—	—	—	—
0·23	+0·05	+0·05	0·11	0·10	0·00	2·11	0·00	−0·01	1·97	−0·04	+0·07	—	—	—	—	—	—
0·36	−0·03	+0·01	0·39	−0·01	−0·03	1·65	−0·13	−0·02	3·52	+0·15	−0·15	—	—	—	—	—	—
0·20	+0·02	+0·03	0·16	0·02	0·00	0·10	+0·04	−0·03	0·23	0·00	0·00	—	—	—	—	—	—
0·23	+0·02	+0·05	0·61	−0·01	−0·01	1·11	−0·08	−0·03	3·29	−0·09	−0·03	0·59	+0·03	+0·05	0·26	−0·01	−0·02
0·21	0·00	+0·02	0·55	−0·05	−0·01	0·11	+0·05	−0·02	0·14	+0·04	+0·01	0·62	+0·02	0·00	—	—	—
0·19	+0·05	+0·04	0·11	+0·02	+0·02	2·03	0·00	0·00	1·97	+0·08	+0·01	—	—	—	—	—	—
0·28	−0·01	+0·03	0·40	−0·02	−0·01	0·98	+0·02	−0·06	3·16	+0·03	+0·10	0·62	+0·02	+0·01	0·25	+0·01	0·00
0·21	+0·01	+0·01	0·92	0·00	+0·03	0·79	+0·01	−0·01	—	—	—	—	—	—	—	—	—
0·18	0·00	+0·01	0·92	0·00	0·00	0·78	+0·04	+0·04	—	—	—	—	—	—	—	—	—
0·18	+0·13	+0·02	0·94	+0·03	−0·03	0·78	+0·03	+0·03	—	—	—	—	—	—	—	—	—
0·28	−0·02	−0·01	1·83	−0·03	+0·05	—	—	—	—	—	—	—	—	—	—	—	—
0·29	−0·01	−0·02	1·98	0·00	−0·04	—	—	—	—	—	—	—	—	—	—	—	—

The melting specifications involved are sufficiently wide to accommodate these errors without the need for an undue amount of checking. In practice values falling nearer to the specification limits then the errors indicated above are checked, and so long as the melting is not unnecessarily close to these limits few such checks are required.

Typical results for these two steels are given in the tables, reproduced on the preceding page, in each of which are detailed the results of twenty-five chemical checks on spectrographic figures obtained in the routine analysis of four hundred casts.

Procedure and Results for Low-alloy Steels

After a considerable amount of experimental work with low-alloy steels, the authors eventually employed a technique essentially similar to that used for the high-alloy steels A and B. The line pairs used are detailed in the following table :—

LINE PAIRS SELECTED FOR THE ANALYSIS OF LOW-ALLOY STEELS.

Element.	Range.	Element Line.	Iron Line.
Silicon	Up to 0·4%	2881·58	2885·93
Manganese	Up to 2·0%	2933·06	2936·90
Chromium	Up to 3·5%	3408·76	3404·36
Nickel.....	Up to 1·5%	3414·77	3413·14
	1·5 to 5·5%	3515·05	3513·82
Molybdenum	Up to 0·8% except for steels with 1% aluminium.	2816·15	2813·61
	Up to 0·5% for steels with 1% Al.*	3170·35	3161·95
Vanadium	Up to 0·3%	3102·30	3100·67

* Necessary because the aluminium interferes with the 2816·15 line.

The results of duplicate determinations on a series of fifty casts, which were also put through normal routine chemical analysis are also tabulated above ; spectra from each sample were taken on two spectrographs, the results being designated as B and C respectively.

It is not practical to specify overall limits of accuracy for the determination of the various elements when dealing with such a varied collection of steels, since these limits vary with the amount of the element present, but a good indication can be obtained for any particular range by inspecting the results. Some portion of the observed differences will, of course, be due to the normal inaccuracies of the chemical analyses, the figures given being taken from ordinary routine determinations, but in general the chemical errors can be taken as small.

Lapping Compounds.

SCIENTIFIC research and the close study of the needs of industry, regarding a satisfactory compound for the lapping of gears and other mechanical moving parts, has led to the conclusion that it is just as necessary to have the right type of compound for a given lapping job as it is to have the proper grinding wheel for a given grinding job.

Much confusion and misunderstanding exists regarding proper standards and practical methods of lapping ; it is therefore noteworthy that the Carborundum Co., Ltd., has directed its research resources to the development of a suitable lapping compound and also to a close study of proper applications and the procuring of scientifically correct results. The results of this work are described in a useful booklet of 54 pages which is devoted entirely to the subject of lapping and lapping compounds. This is a new addition to the admirable series of Carborundum publications, and it should prove of great assistance to those on war work who are interested in fine finishes. Copies may be obtained on application to the Carborundum Co., Ltd., Trafford Park, Manchester, 17.